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**Toledo et al.**

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(54) **POWER METERING AND CONTROL  
SYSTEM ADAPTABLE TO  
MULTI-STANDARD DEVICE**

USPC ..... 320/101; 323/282; 136/244  
See application file for complete search history.

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(56) **References Cited**

U.S. PATENT DOCUMENTS

2,987,564 A 2/1958 Imelmann  
3,081,364 A 3/1963 Henderson et al.

(Continued)

OTHER PUBLICATIONS

TEG Power, "TEG Power Brick (AKA "Ice TEG")" retrieved from  
Internet <http://www.tegpower.com/pro2.htm> on Apr. 20, 2012, 3  
pages.

(Continued)

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21, 2010, provisional application No. 61/738,345,  
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Y02B 70/1466

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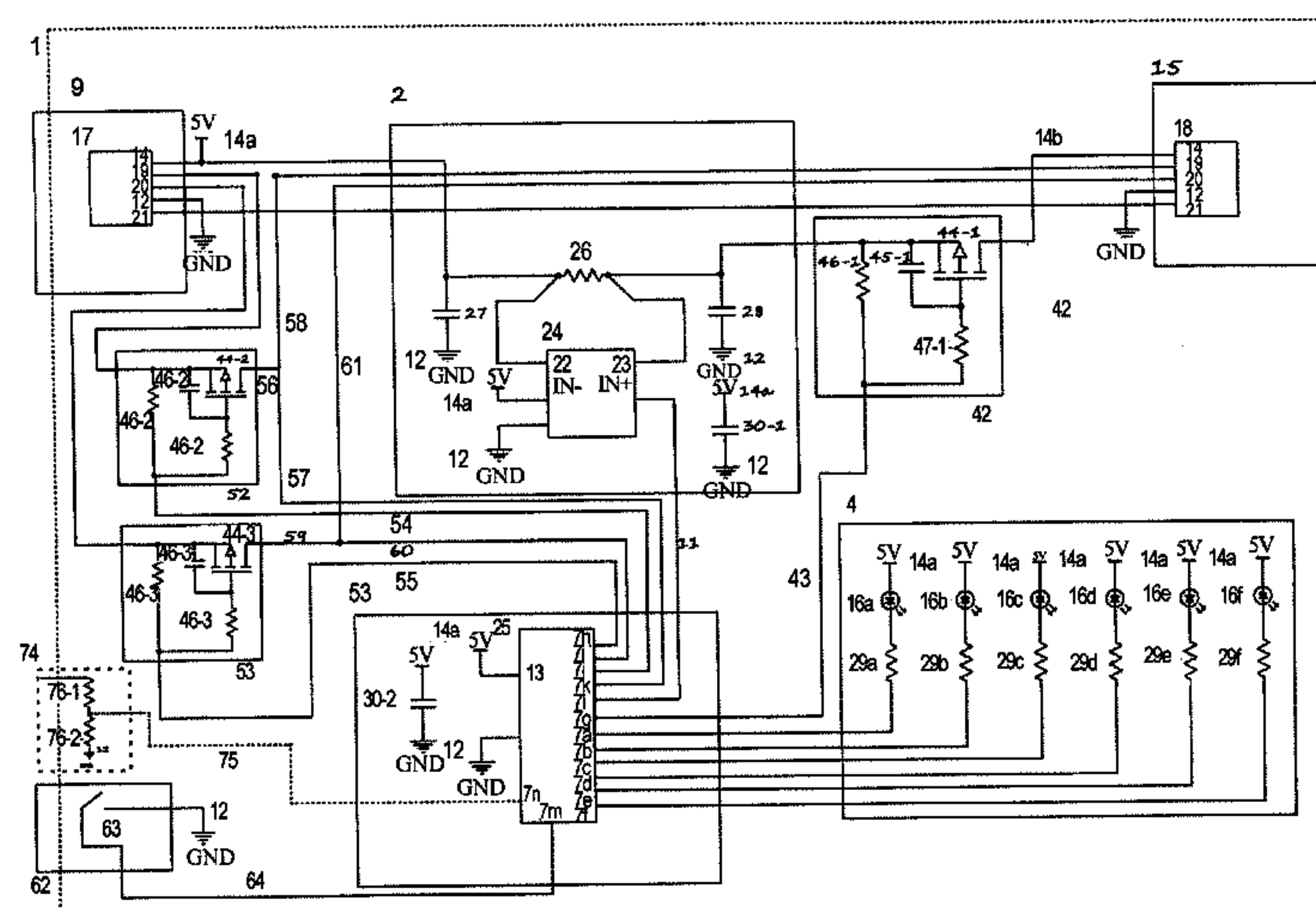
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(57) **ABSTRACT**

A power control device has a voltage-regulator from power  
source to load, the load configurable to receive power at  
least at a first or second rate. The device has monitor  
circuitry to measure power; signal circuitry for signaling a  
power-reception rate to the load; and circuitry for resetting  
the load when the power source is overloaded. The device  
resets the load periodically to the second rate when the load  
is at the first rate. In embodiments, the power source is a  
thermoelectric generator or solar panel. In embodiments, the  
load couples through a USB connector. A companion  
method of charging smart loads includes applying power to  
the load; communicating power available to the load; con-  
figuring a battery charger in the load to absorb an amount of  
power less than that available; monitoring power, determin-  
ing when changed configuration may optimize charging time  
of a smart load battery; and resetting the smart load to  
optimize current.

**14 Claims, 16 Drawing Sheets**



(51)	<b>Int. Cl.</b>								
	<i>H01L 31/042</i>	(2014.01)				2008/0197802	A1 *	8/2008	Onishi ..... H02J 5/005 320/106
	<i>H02J 7/00</i>	(2006.01)				2009/0205694	A1	8/2009	Huettner et al.
	<i>H02M 3/156</i>	(2006.01)				2011/0284047	A1	11/2011	Johnson et al.
	<i>H01L 35/30</i>	(2006.01)				2012/0181971	A1	7/2012	Birkeland et al.

OTHER PUBLICATIONS

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,082,276	A	3/1963	Corry et al.	
3,123,726	A	3/1964	Maynard	
3,321,840	A	5/1967	Pedersen	
3,384,806	A *	5/1968	Hartman .....	G05F 1/56 136/291
5,311,112	A *	5/1994	Creaco .....	H02J 7/0021 320/119
5,544,488	A	8/1996	Reid	
5,552,696	A *	9/1996	Trainor .....	H02J 3/1878 323/255
6,046,582	A *	4/2000	Sanelli .....	G01R 15/125 324/115
6,134,130	A *	10/2000	Connell .....	G06K 19/0701 363/70
6,528,957	B1 *	3/2003	Luchaco .....	H05B 37/034 307/31
6,588,419	B1	7/2003	Buezis et al.	
6,787,691	B2	9/2004	Fleurial et al.	
2004/0062058	A1 *	4/2004	Hann .....	H02J 1/102 363/15
2007/0290555	A1 *	12/2007	Caren .....	H02J 7/0055 307/31

Stealth Power Systems, “Multi-Purpose Power System,” retrieved from Internet <http://www.stealthpowersystems.com> on Apr. 20, 2012, 1 page.

Termo-Gen AB, “Thermoelectric Mobile Charger,” retrieved from Internet <http://www.tragia.se>, applicant admits prior art.

Hatsuden-Nabe Thermoelectric Cookpot Keeps Your iPhone Battery Charged, dated Jun. 14, 2011, retrieved from the Internet <http://www.tuaw.com/2011/06/14/hatsuden-nabe-thermoelectric-cookpot-keeps-your-iphone-battery-c/> on Apr. 20, 2012, 3 pages.

Biolite, “Introducing the All New Biolite CampStove,” retrieved from the Internet <http://biolitestove.com/BioLite.html>, on Apr. 20, 2012, 1 page.

Tellurex World Pot, “Remote Village—Dead Cell Phone—Need Help Now, If Your Can Start a Fire, Now You Can Place a Call,” Jul. 8, 2011, retrieved from the Internet <http://www.tellurex.com/about/world.sub.--pot.php> on Apr. 20, 2012, 8 pages.

Emad Hanna, “Camping Pot Let’s You Cook Up Some Electricity”, Jun. 22, 2011, Discovery News, <http://news.discovery.com/tech/camping-pot-lots-you-cook-up-some-electric-ity-110622.html>.

U.S. Appl. No. 13/332,237 Select File History dated Oct. 28, 2013, 19 pages.

\* cited by examiner

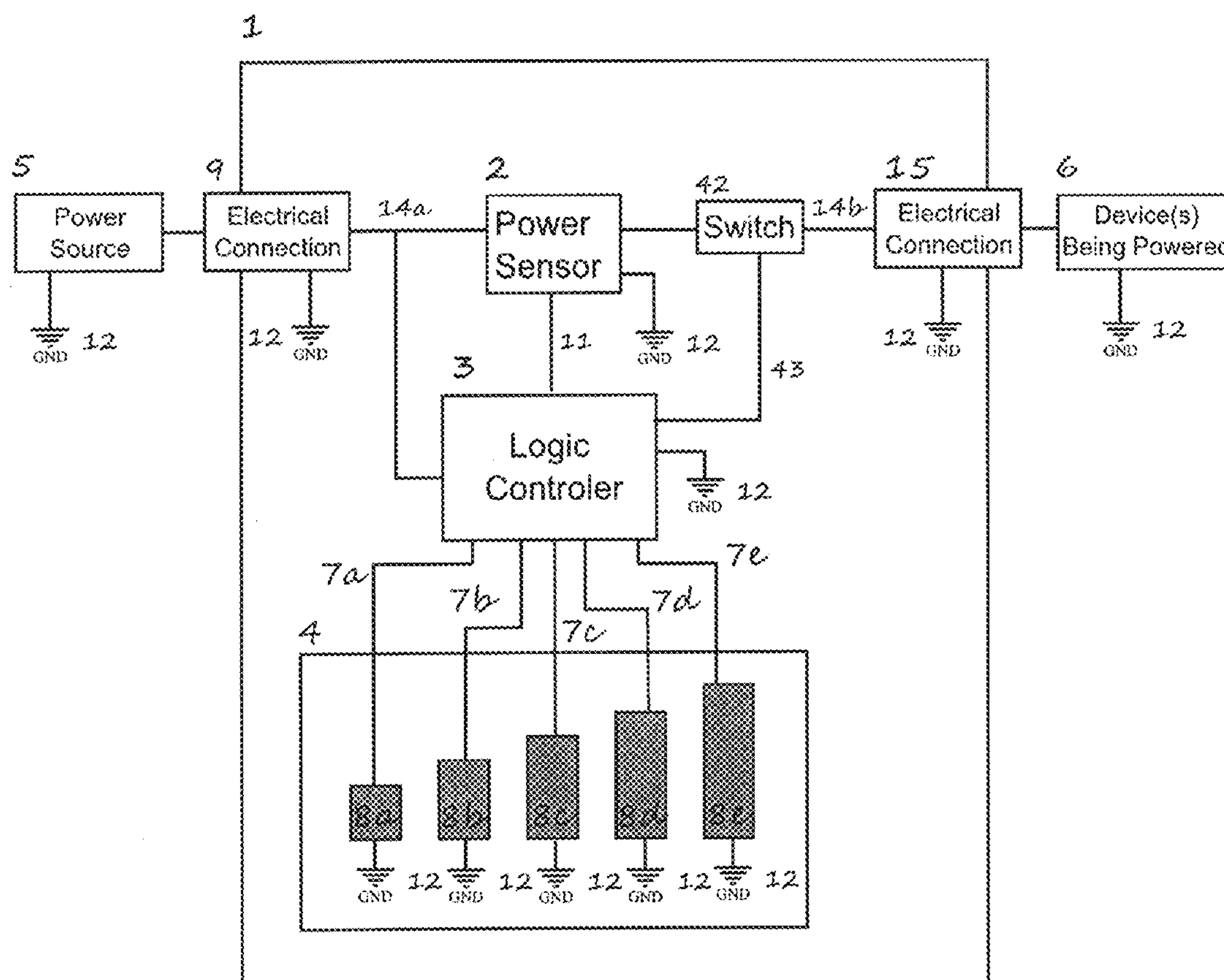


Fig. 1



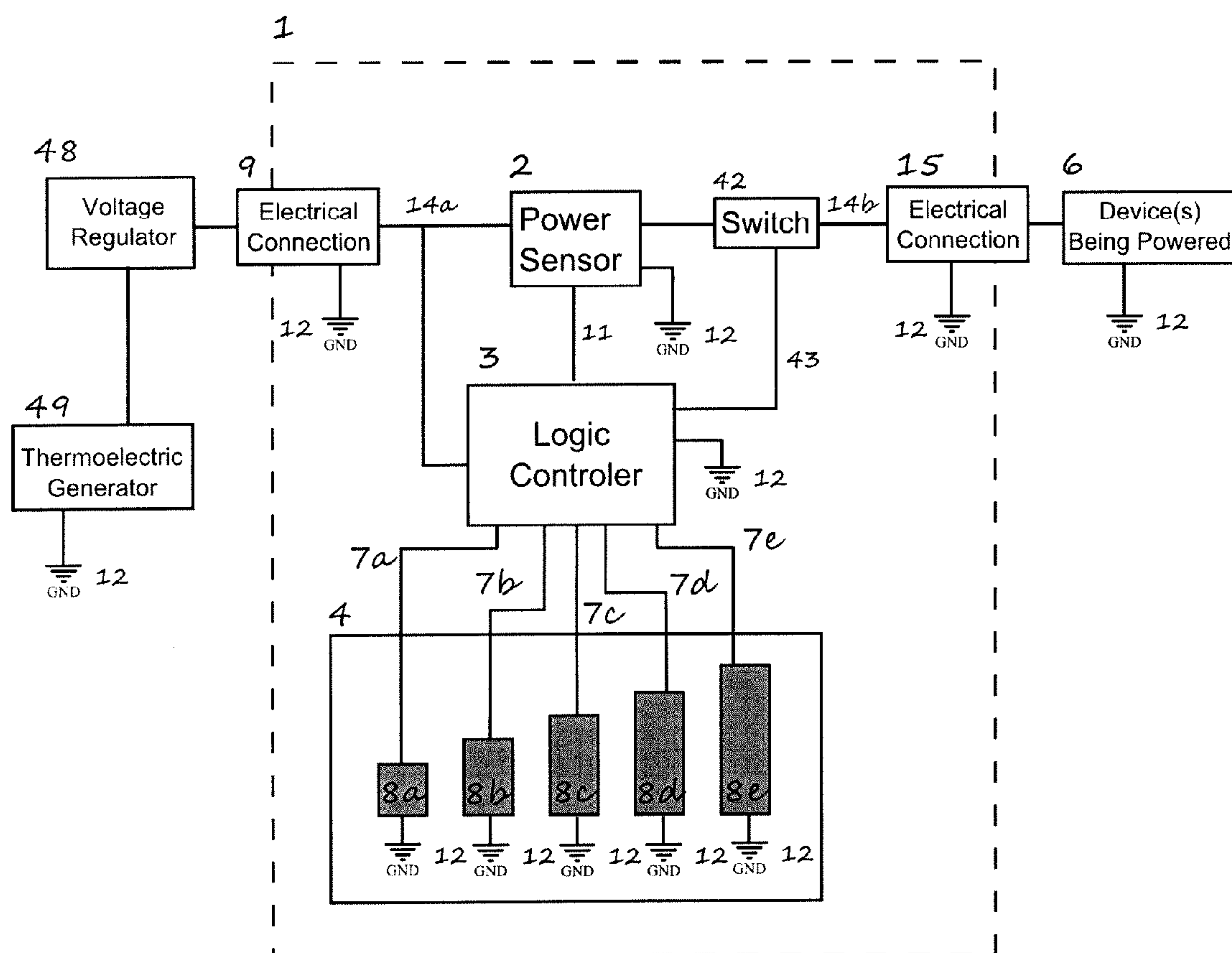


Fig. 2

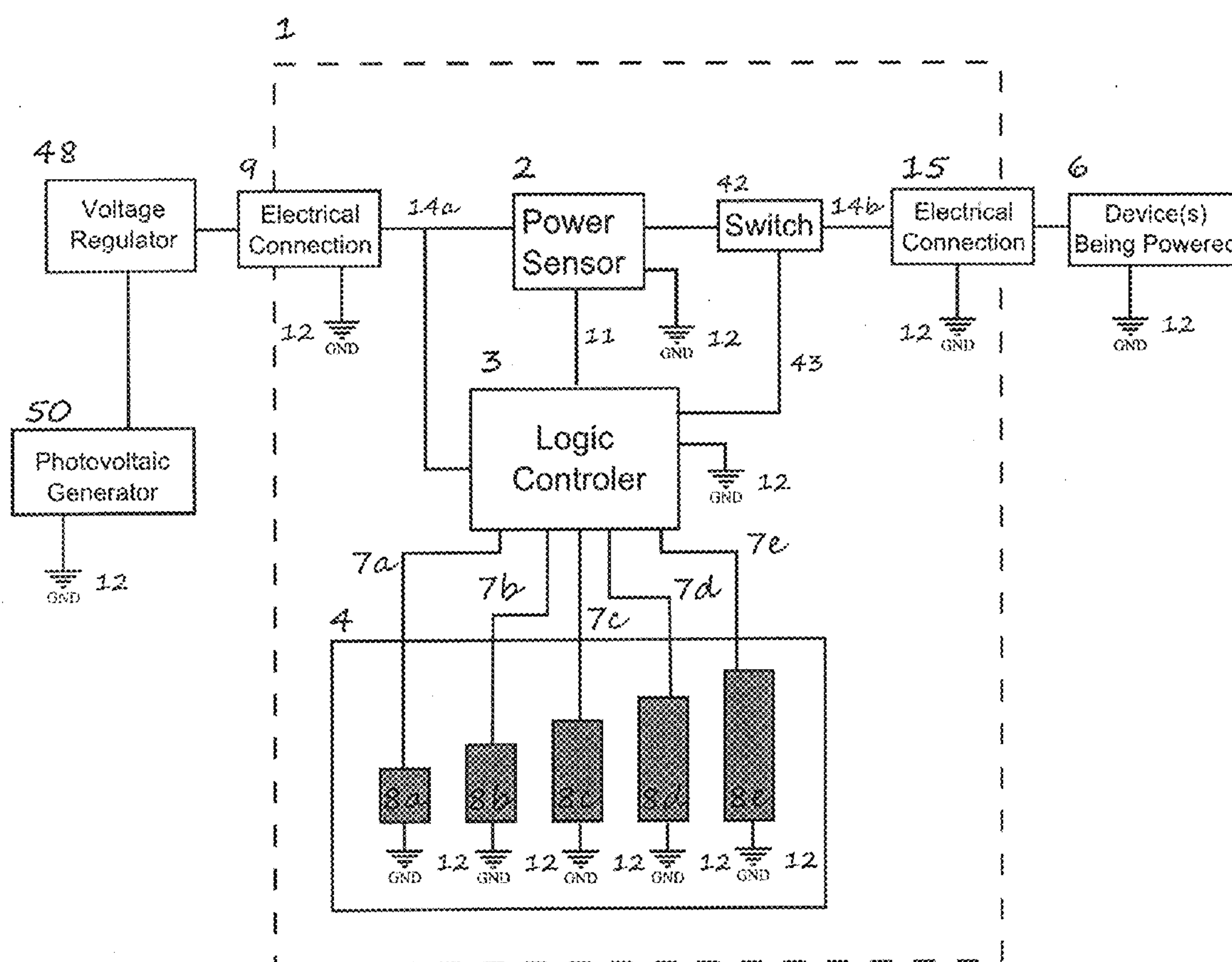


Fig. 3

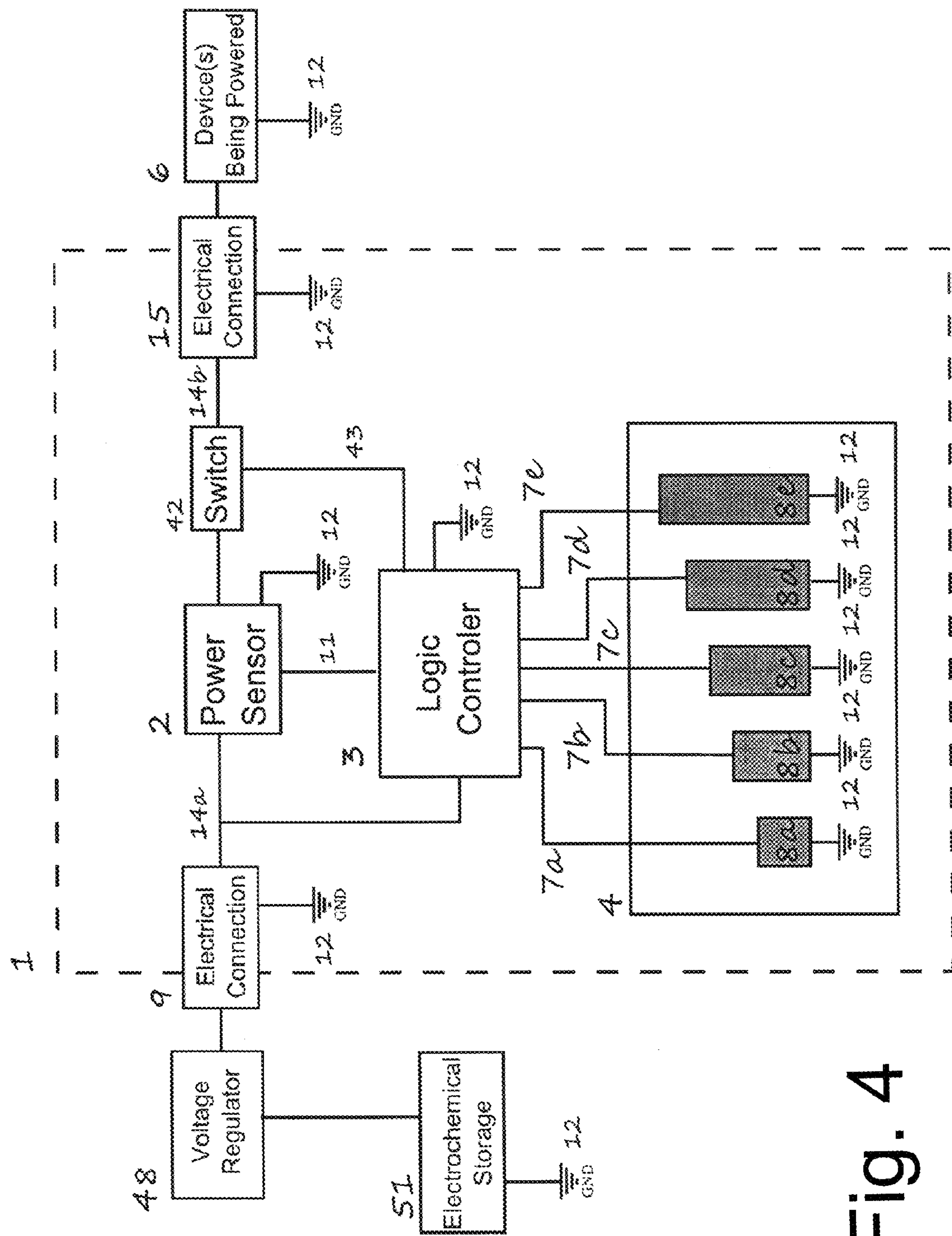


Fig. 4

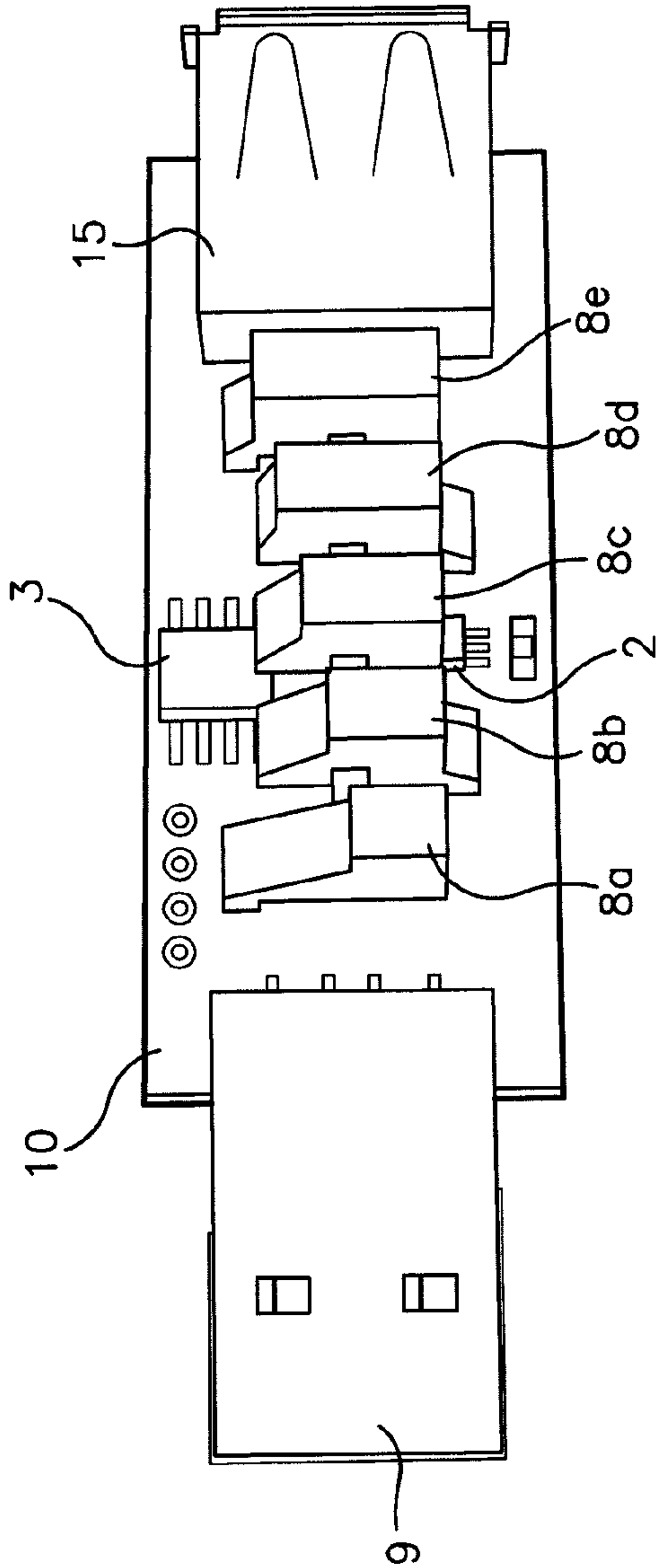
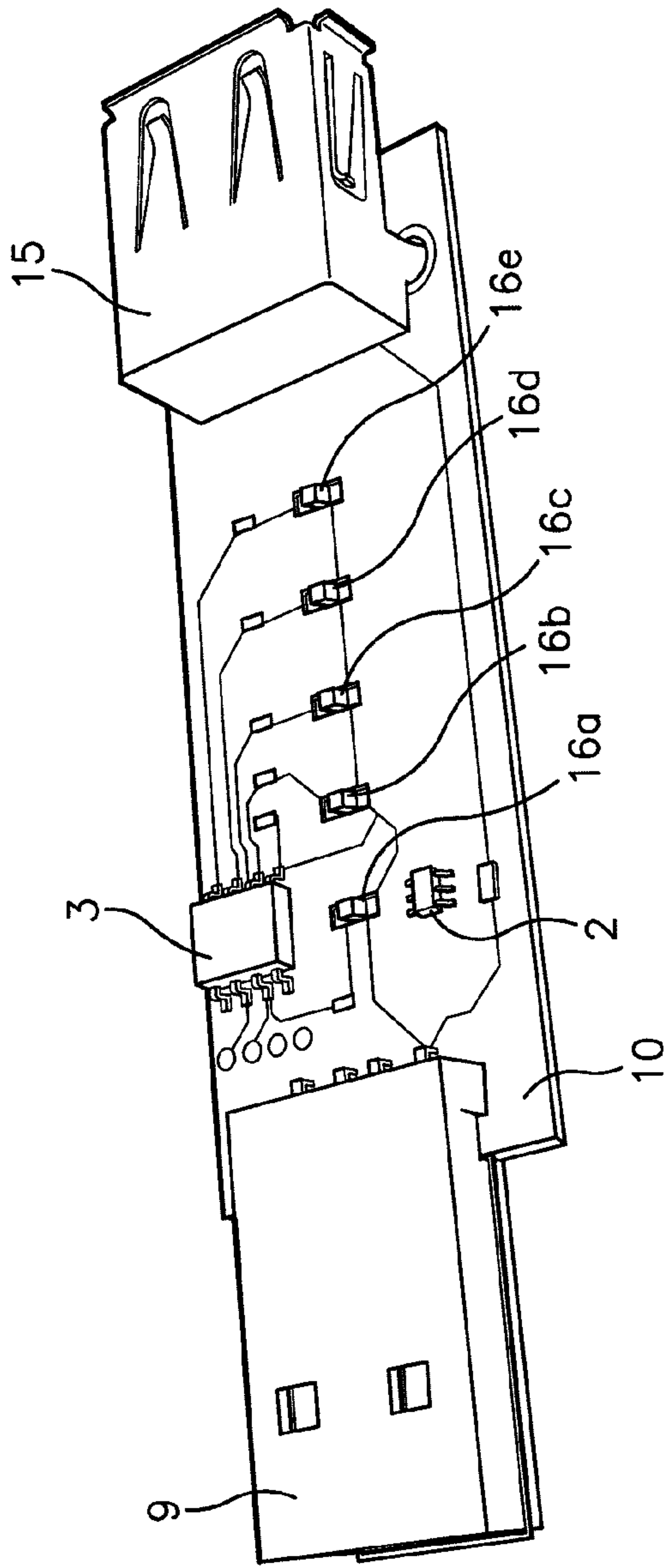


Fig. 5

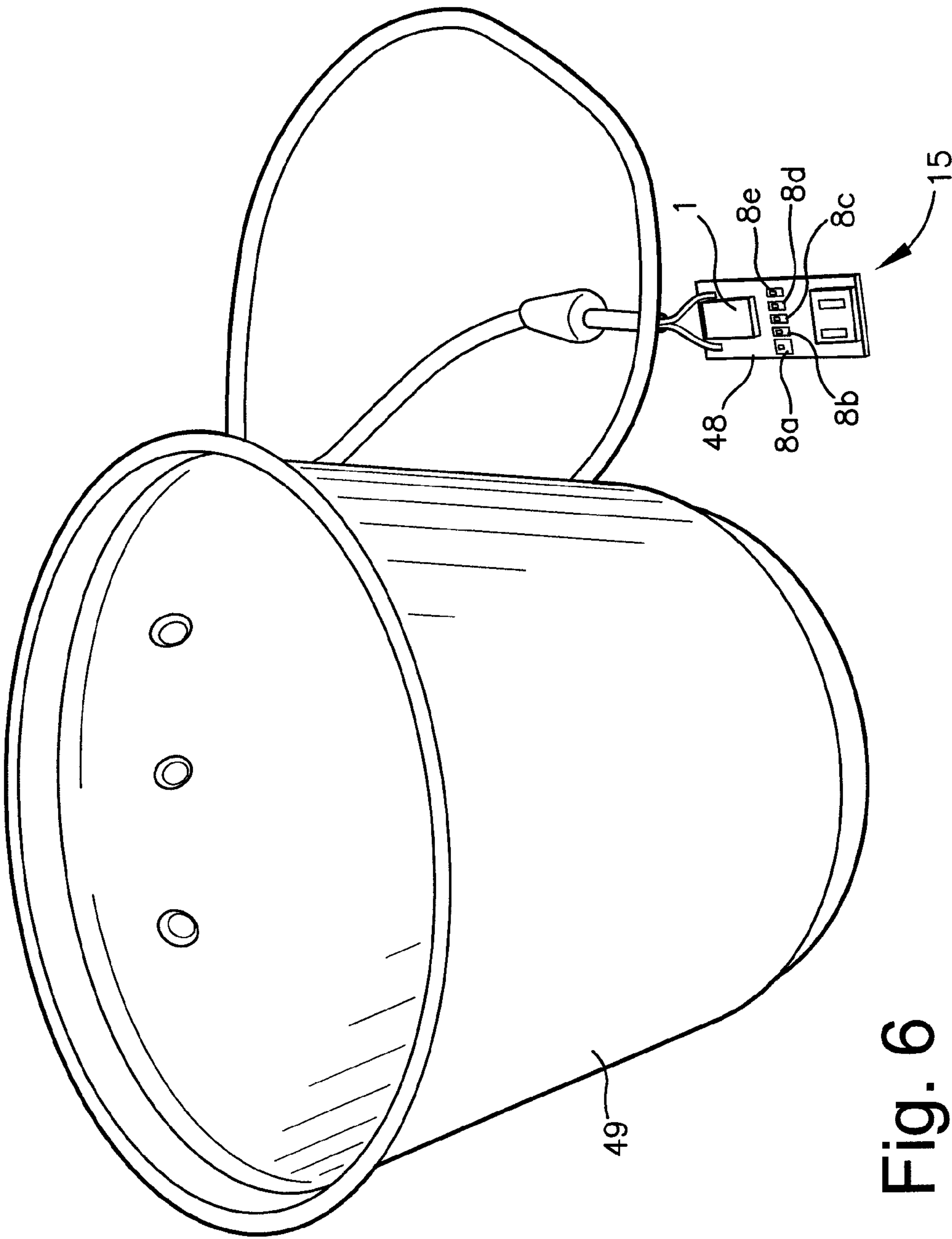


Fig. 6



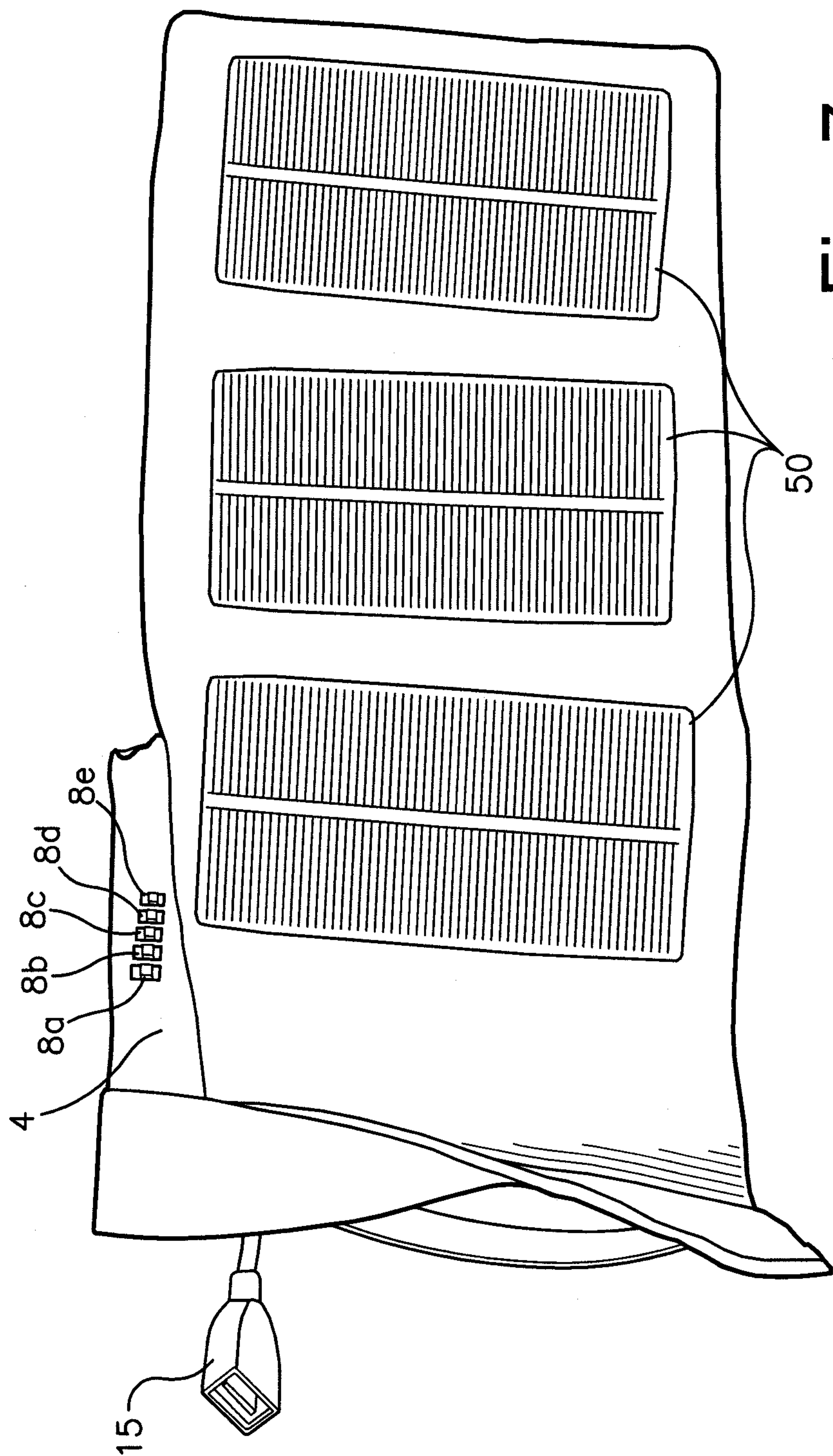


Fig. 7

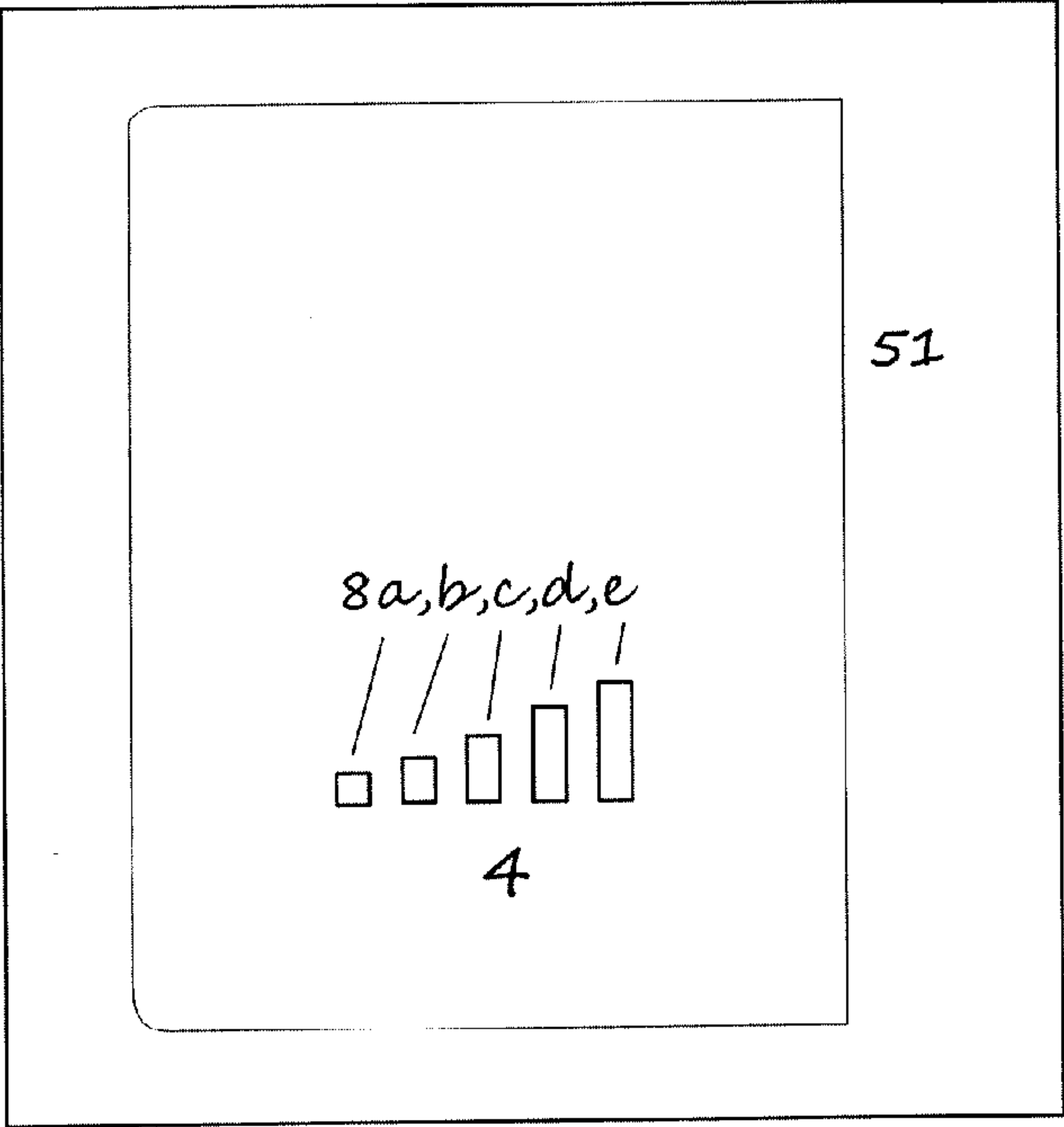


FIG. 8A

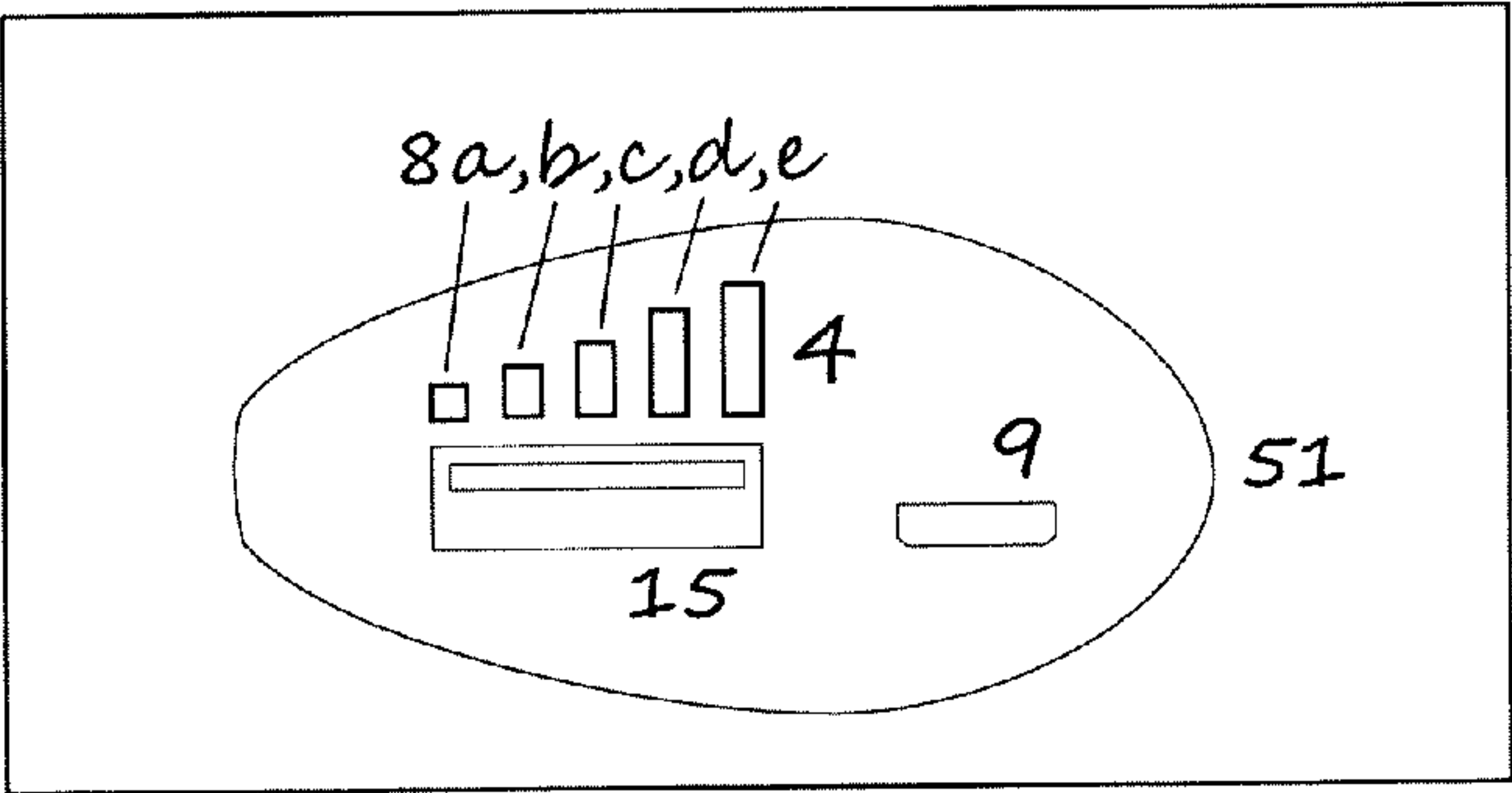


FIG. 8B

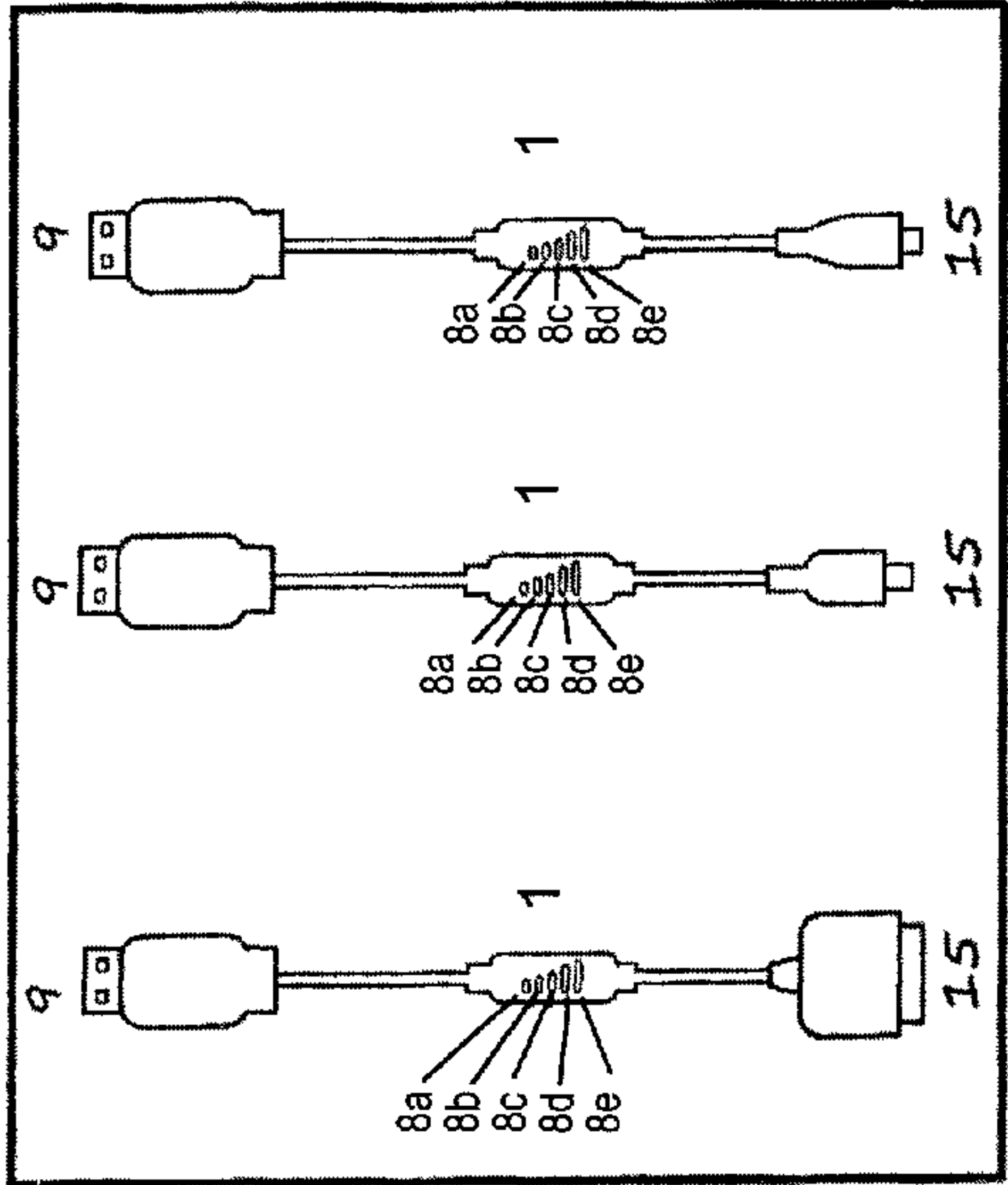


Fig. 9b

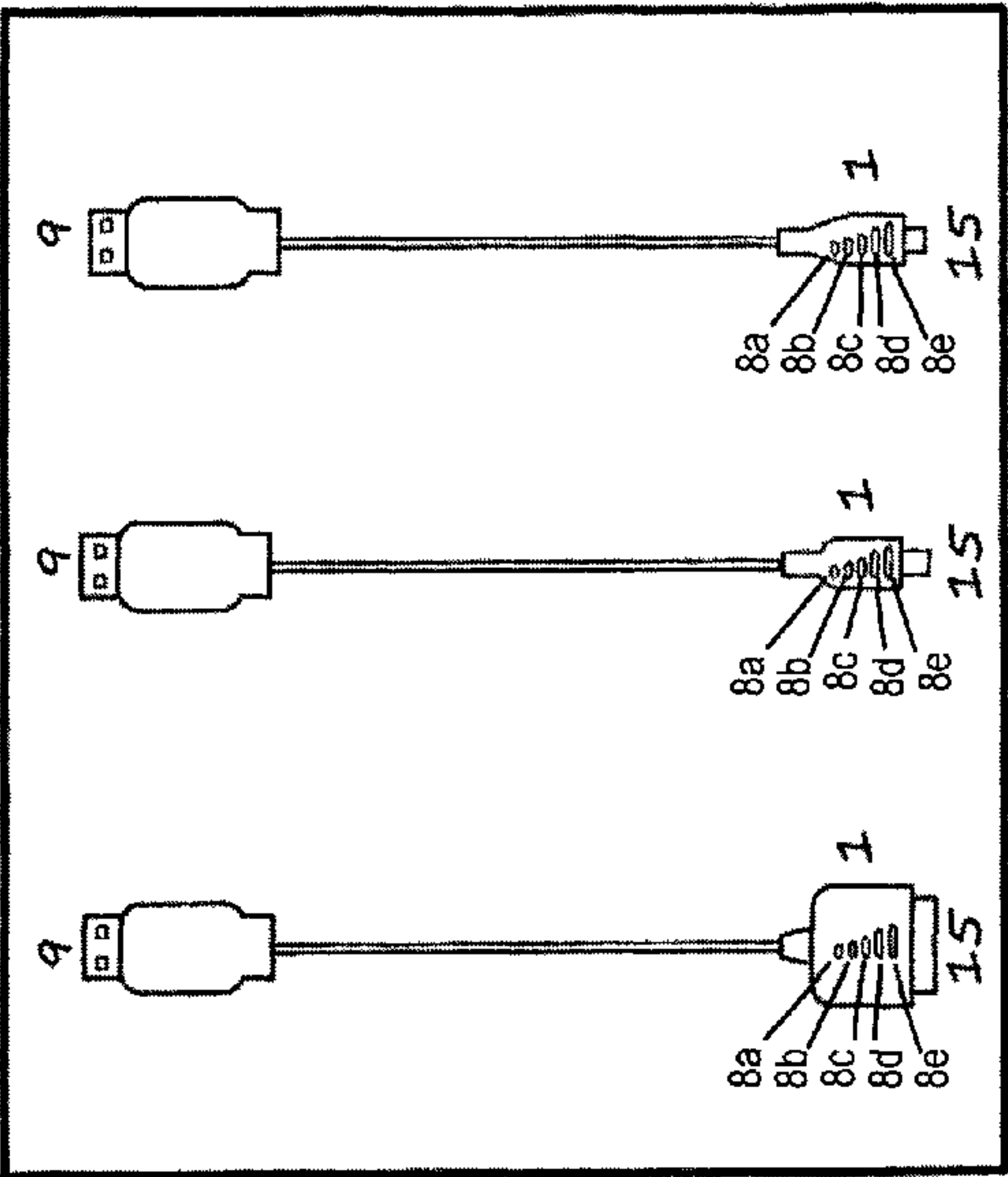


Fig. 9c

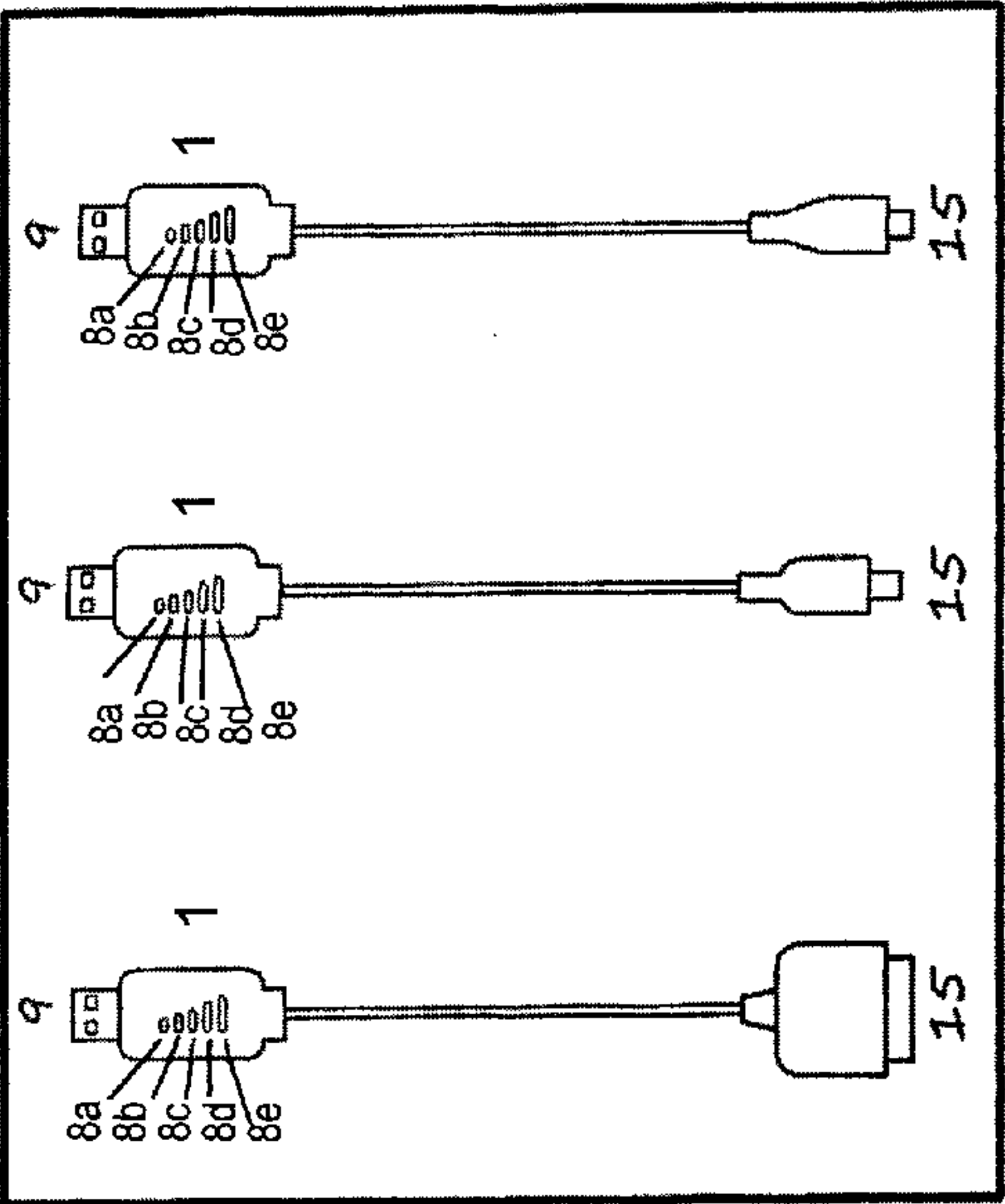


Fig. 9a

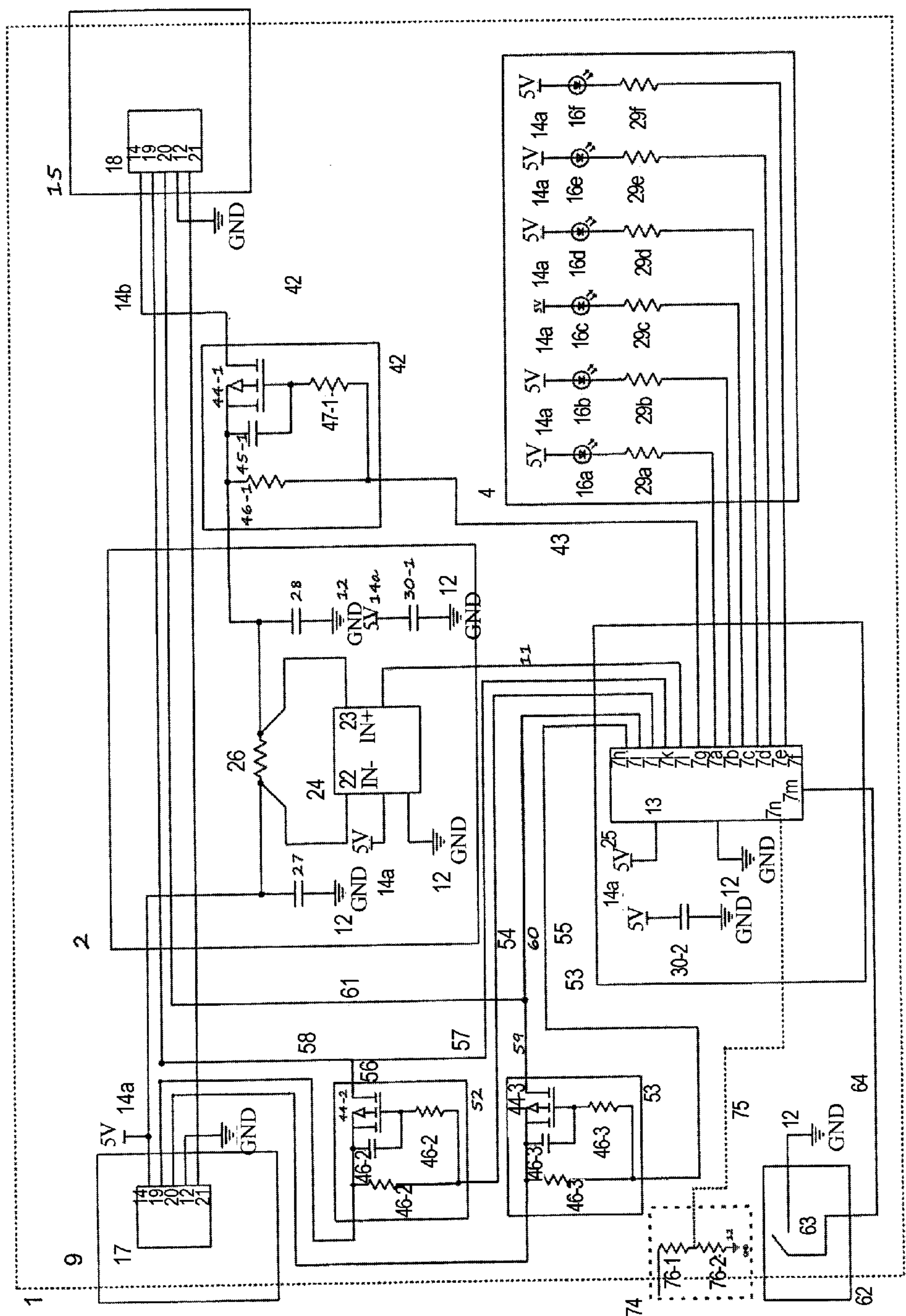
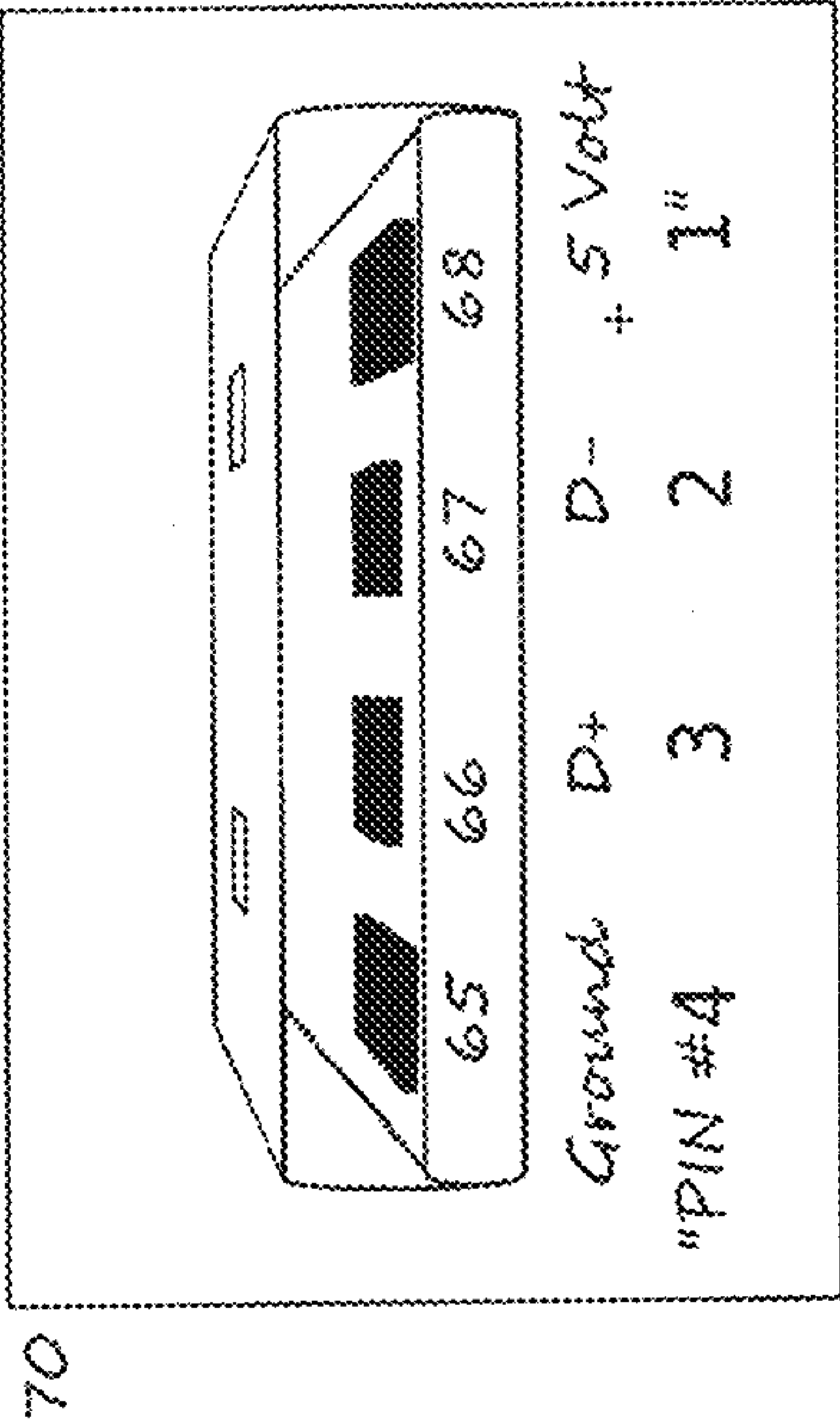


Fig. 10



Standard USB Type A



Industry Standard USB Type B

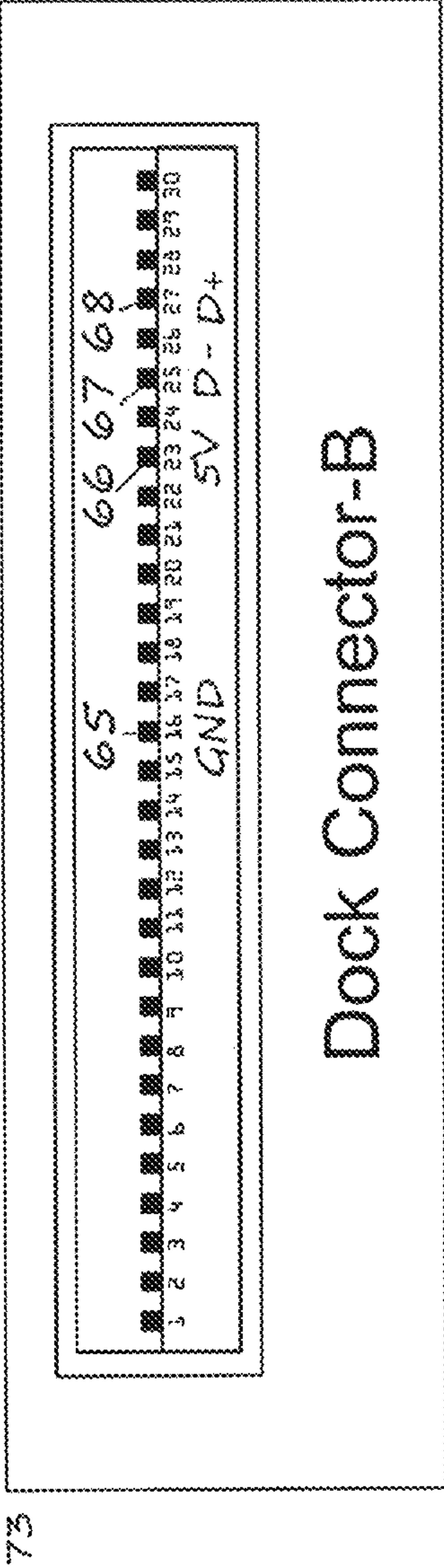
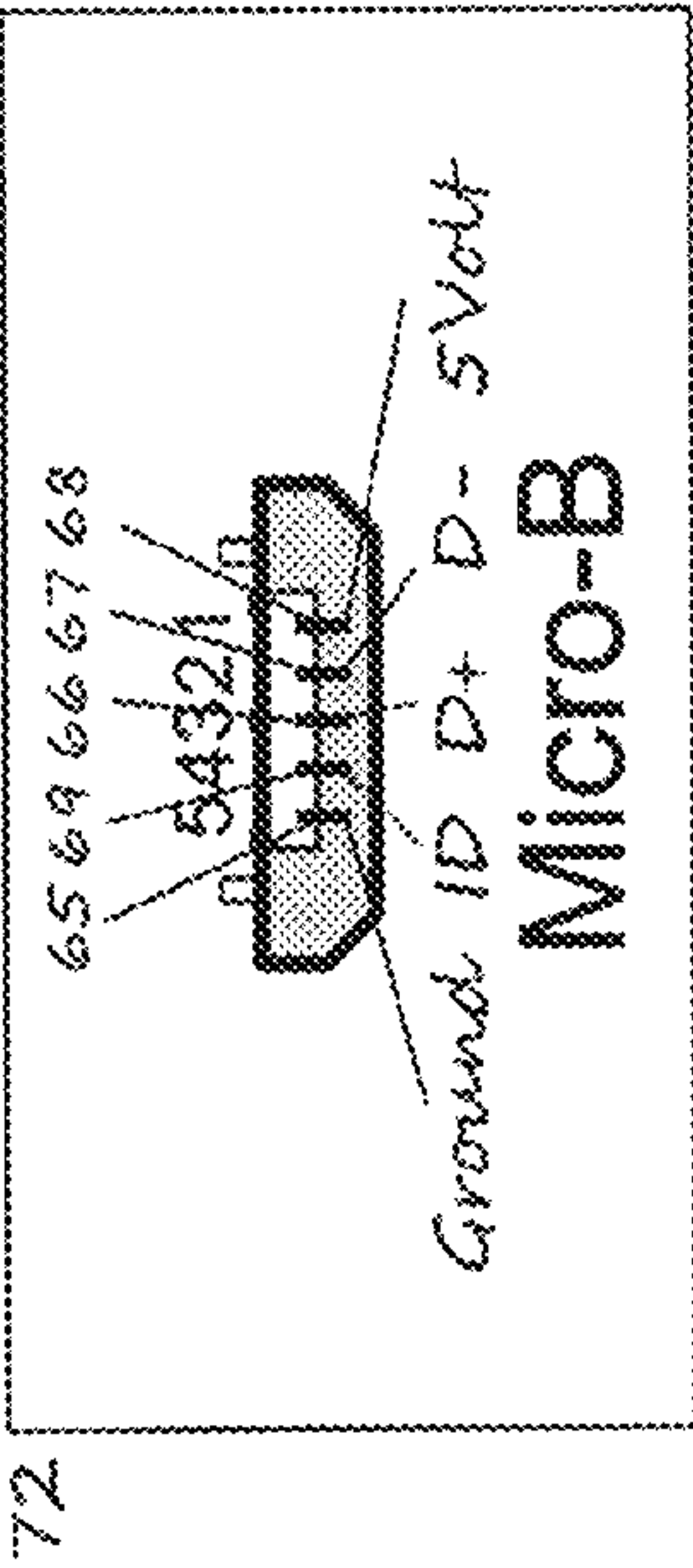
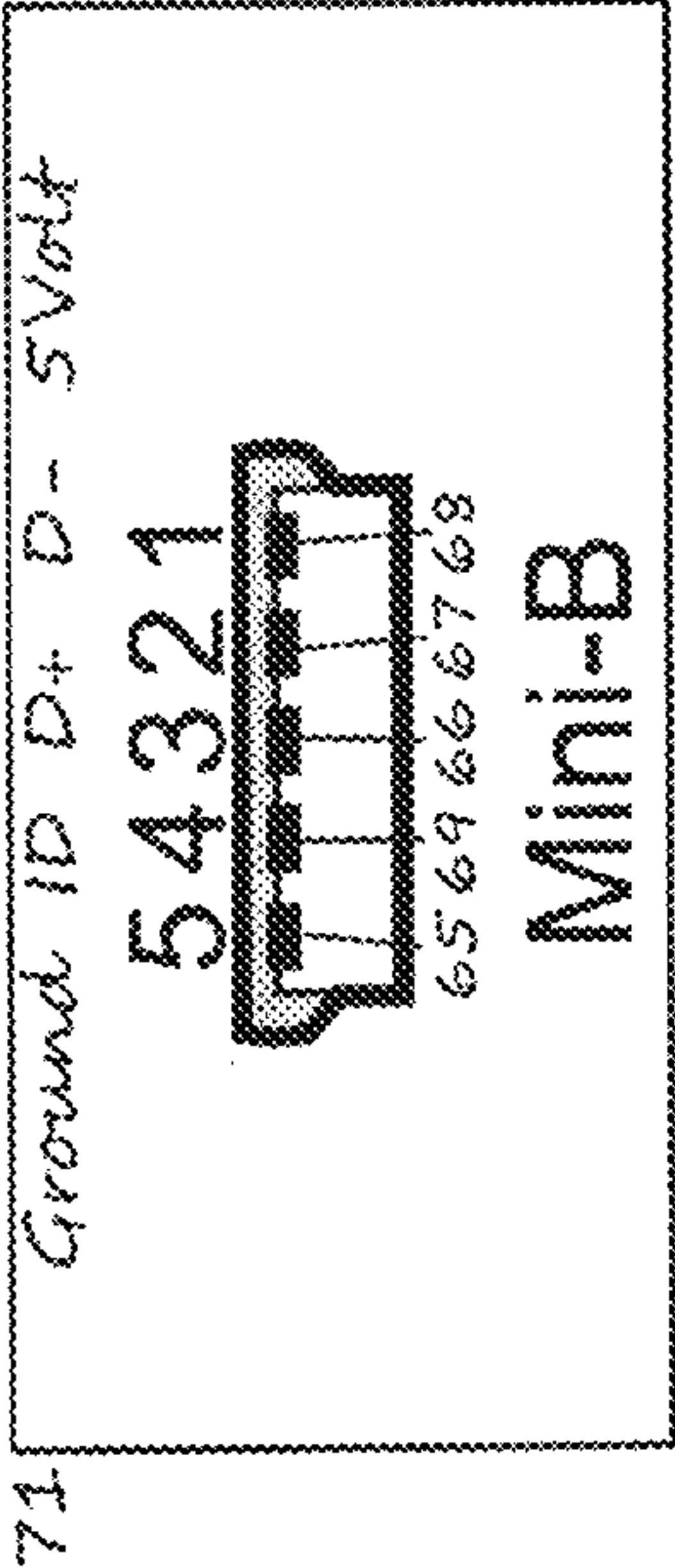
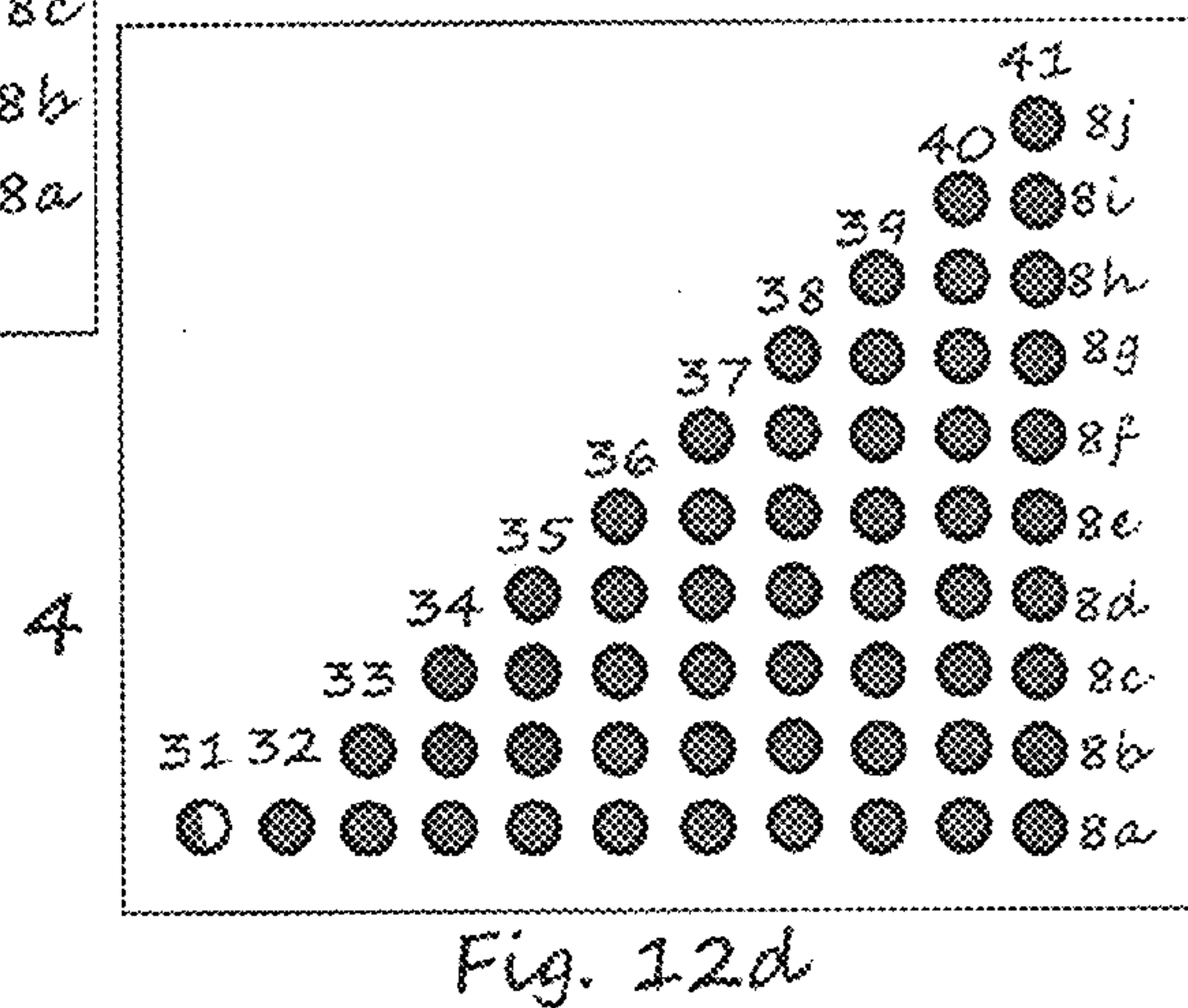
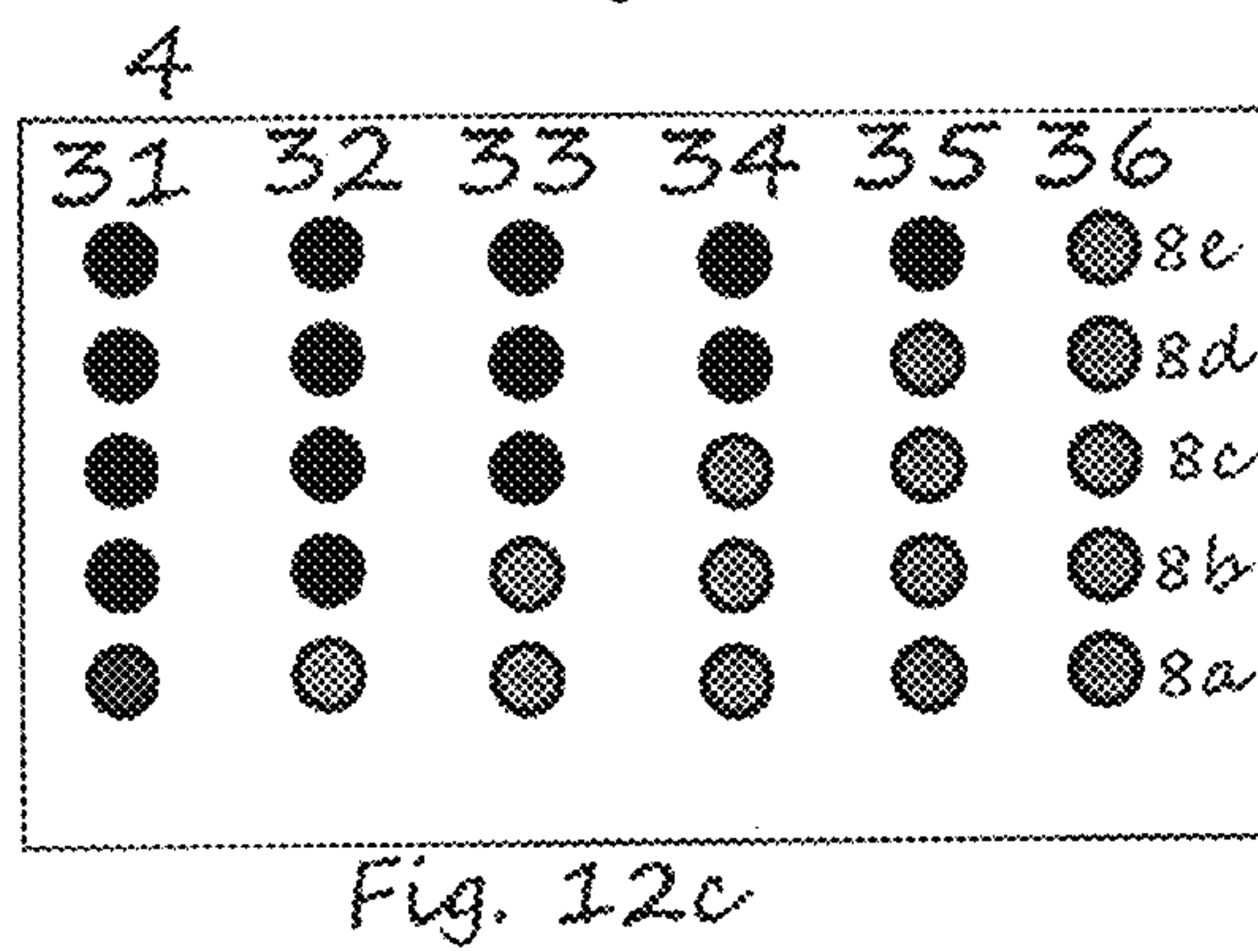
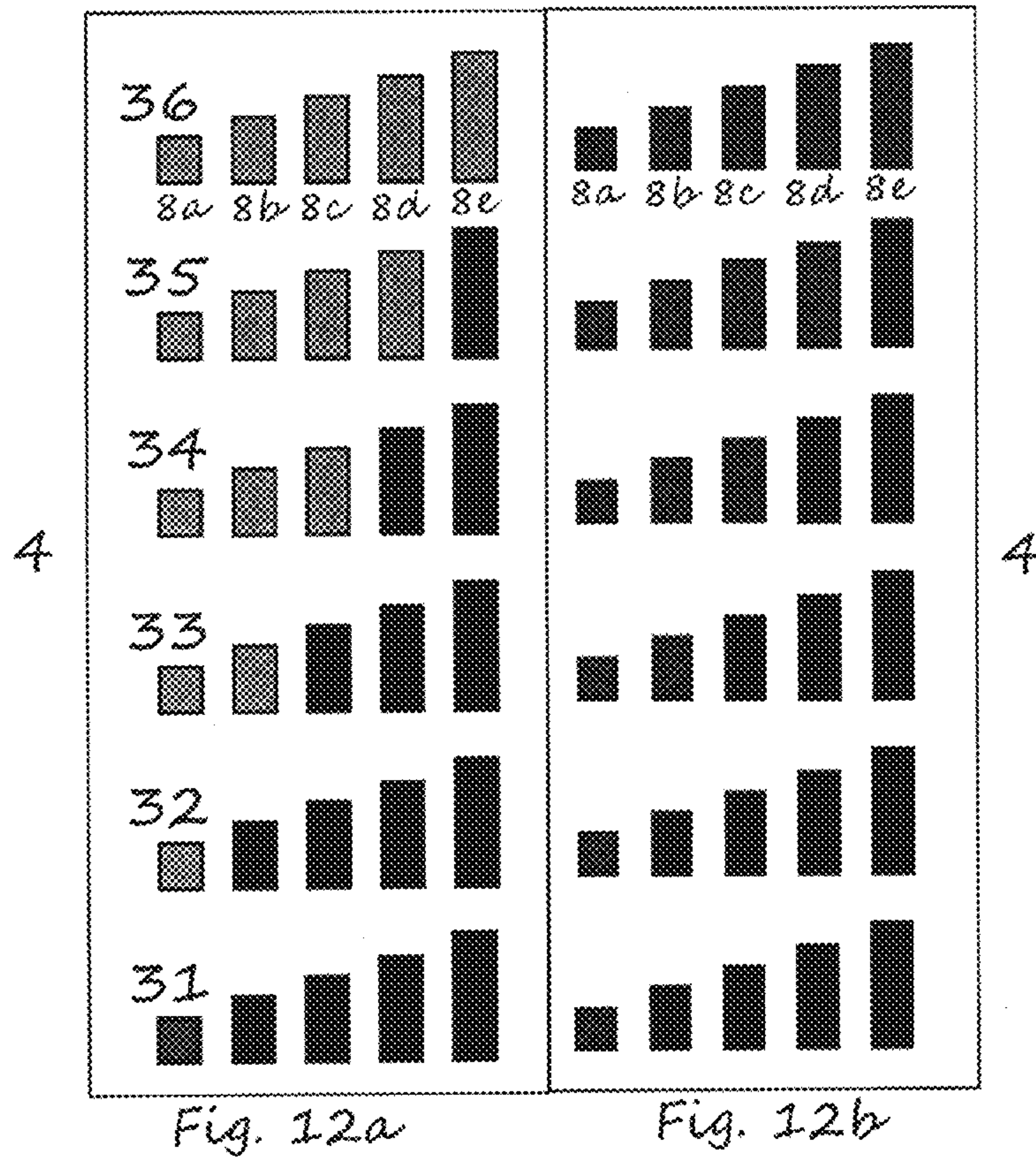
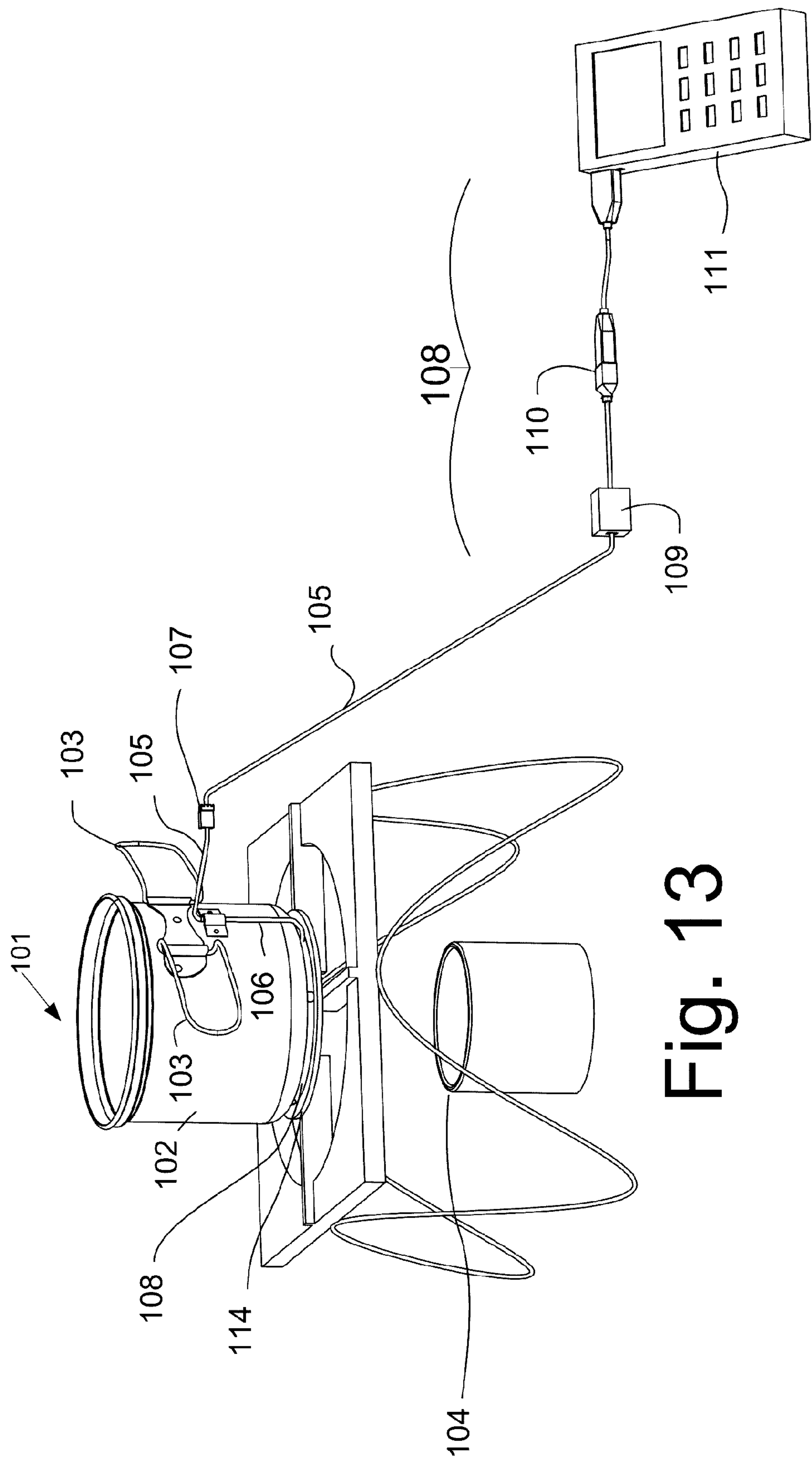


Fig. 11







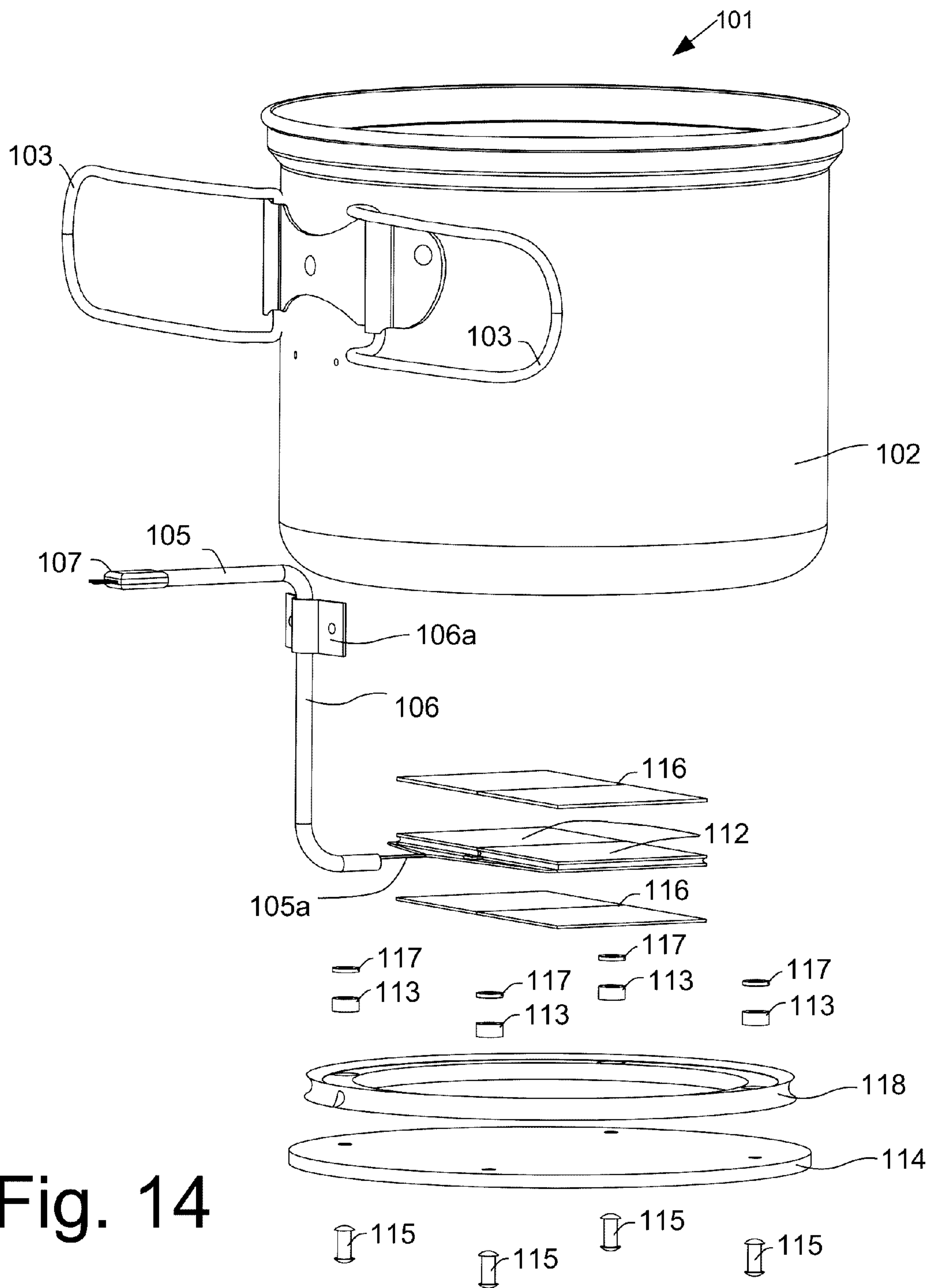


Fig. 14



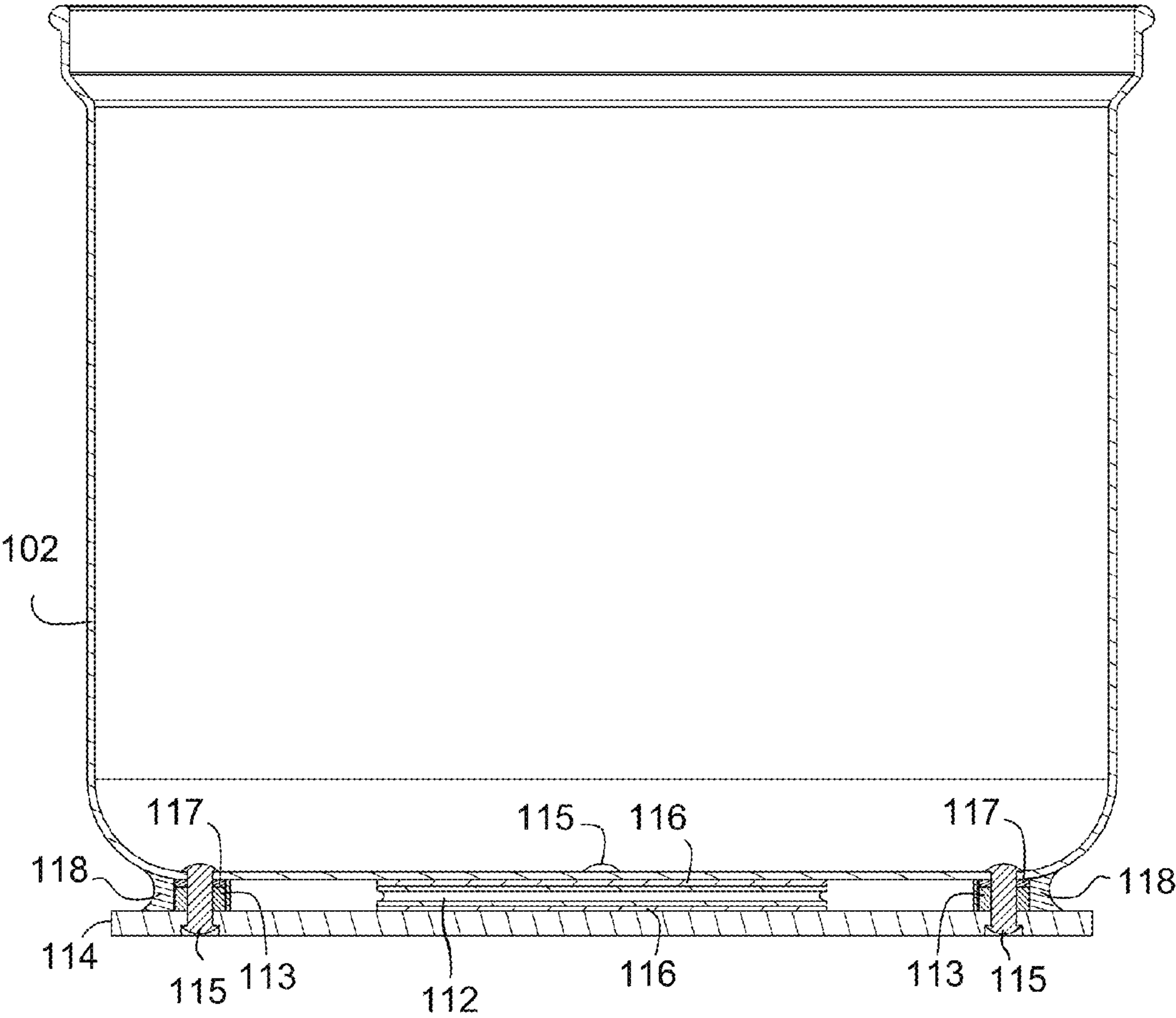
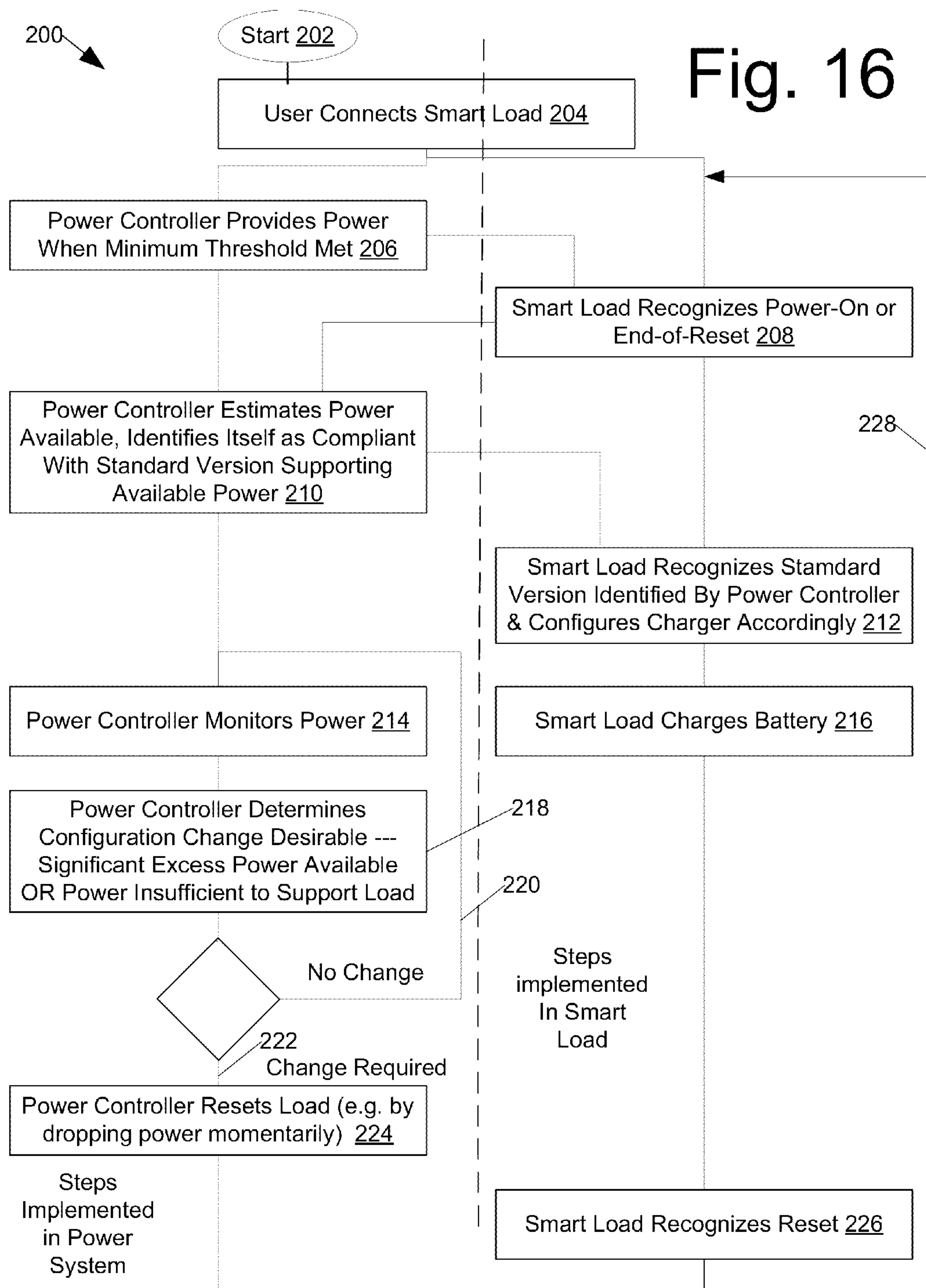


Fig. 15





## 1

**POWER METERING AND CONTROL  
SYSTEM ADAPTABLE TO  
MULTI-STANDARD DEVICE**

RELATED APPLICATIONS

This application is a continuation-in-part U.S. patent application Ser. No. 13/332,237 filed 20 Dec. 2011, which claims priority to priority to U.S. Provisional Patent Application Ser. No. 61/425,699 filed Dec. 21, 2010. This application also claims priority to U.S. Provisional Patent Application 61/738,345, filed Dec. 17, 2012, and claims priority to U.S. Provisional Patent Application 61/862,791, filed Aug. 6, 2013. This application also claims priority to U.S. Provisional Patent application 61/879,987 filed 19 Sep. 2013. The entire contents of the aforementioned patent applications are incorporated herein by reference.

FIELD OF THE INVENTION

The invention relates generally to the field of power-metered charging systems for devices configured to comply with multiple standards.

SUMMARY

A power control device has voltage-regulation circuitry from a power source to a load, the load being configurable to receive power at least at a first or second power-reception level. The device also has circuitry configured to monitor power; circuitry configured to signal circuitry of the load of a power-reception level; and circuitry configured to reset the load when the power source cannot provide sufficient power to the load. The device is configured to reset the load periodically reset the load to the second power reception level when the load is receiving power at the first power-reception level.

A method of operating a smart load with a charging system includes applying power to the load; communicating an amount of power available to the load; configuring a battery charger of the smart load to use an amount of power less than the amount of power available; monitoring power, determining when a change in configuration is required to optimize charging time of a battery in the smart load; and resetting the smart load to optimize load current.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts a conceptual layout of an embodiment of the invention.

FIG. 2 is a detailed circuit diagram of one embodiment of the invention.

FIG. 3 is a detailed circuit diagram according to another embodiment of the invention.

FIG. 4 is a detailed circuit diagram according to another embodiment of the invention.

FIG. 5 is a perspective view of the Intuitive Power Display Human Interface device of FIG. 1.

FIG. 6 is a perspective view of the Intuitive Power Display Human Interface device of FIG. 2.

FIG. 7 is a perspective view of the Intuitive Power Display Human Interface device of FIG. 3.

FIGS. 8A and 8B are top views of the Intuitive Power Display Human Interface device of FIG. 4 as installed in an assembly.

## 2

FIGS. 9a-c are orthographic view of USB charging cables as part of the Intuitive Power Display Human Interface device according to several embodiments.

FIG. 10 is a detailed circuit diagram according to one embodiment of the invention.

FIG. 11 depicts standard USB related connectors.

FIGS. 12a-d shows an output or display part of the Intuitive Power Display Human Interface device according to several embodiments.

FIG. 13 is a perspective view of one embodiment of a portable thermoelectric power generation system in accordance with the teachings of the current invention;

FIG. 14 is an exploded view of the portable thermoelectric power generation system of FIG. 13; and

FIG. 15 is a side view showing the interrelationship between some of the components of the portable thermoelectric power generation system of FIG. 13.

FIG. 16 is a flowchart of a method of battery charging implemented by embodiments of the system of FIG. 1-3 and FIG. 14.

DETAILED DESCRIPTION

A recent increase in battery powered mobile devices (cellphones, radios, lights, laptops, etc. . . .) with relatively low power requirements (<100 W) has caused a rise in mobile methods of electrical power sources (e.g. batteries, solar panels, crank generators, thermoelectric generators, fuel cells). Simultaneously, connections for particular voltages have become globally standardized, such as USB (5V) and auto/marine outlets (12 V); however, electrical current and therefore power ( $P=V \times I$ ) is not similarly standardized for these same connections. For example, with the Universal Serial Bus (USB) connection there are three categories of USB 1.0, 2.0, and 3.0, each with their own specification, with three different maximum currents 500 mA, 1,000 mA, and 3,000 mA respectively, all of which are standardized at five volts. All three categories use 5V and are physically inter-connectable. The invention described herein provides, among other things, a simple, intuitive, cost effective means of determining the current/power being supplied through a voltage standardized port.

It is particularly useful to know the instantaneous current draw when charging a mobile device in the field from a portable generator due to the wide variety of current requirements of devices and output capabilities of generators. Many mobile devices will display "charging" when plugged into power sources that are inadequate to charge the device at the expected rate. For example, a tablet requiring 2,000 mA charging from a 400 mA hand-crank generator may display "charging" when plugged into the generator even though the generator does not provide enough power to charge the device. In the described scenario, it is most likely that the hand-crank will be incapable of increasing the battery charge of the tablet while the tablet is turned on (consuming 2 W<), though it may indicate active charging. When energy is scarce, having realistic expectations of charging times, and therefore running time, is extremely valuable.

Many power generation devices also have variable output. For example, a thermoelectric generator has output that depends greatly on a temperature difference between a heated surface and a cooler surface, if a campfire is used to heat the heated surface, the temperature of the heated surface will vary with many factors, including proximity and type of fuel, airflow, and stage of campfire, throughout the life of the



campfire. Similarly, a solar panel has output that varies with time of day, angle to the sun, cloud, shade, latitude, and so forth.

However, the reverse scenario, i.e., when the mobile device consumes less power than available in the mobile generator, may also occur. For example, consider a mobile phone charging at 1,000 mA from a solar panel capable of outputting 2,000 mA. In this scenario the user could be charging 2 mobile phones or 1 larger battery capable of harnessing the full power output of the 10 W solar panel. Considering that batteries in mobile devices charge at different currents during different regimes of their charge cycle, the maximization of power usage from the source becomes increasingly complicated. Furthermore, with the increasing use of LED lighting, devices consuming <5 W are widespread, the possible combinations of devices consuming a total of <10 W (common voltages, differing currents) becomes staggering.

Additional benefits of an intuitive power display human interface device include its use maximizing the current output of a power generation system which can be affected with human intervention in accordance to the feedback from the power display. Many portable power sources, particularly generators, have power outputs that are dependent on the current local environment, and the user may make adjustments to either the generation system or the environment to influence the power output of the generator.

This may be illustrated by the case of a solar panel that is partially shaded or oriented non-optimally towards the sun. Without feedback the user will not know that the power output of the generator is very low, even though the device they intend to charge may indicate that it is in the charge state. Using the human interface device, the user knows the device is charging below specification, and may reposition the solar panel. During repositioning, the intuitive power display human interface device may actively display optimal positioning through increase of illuminated bars or improper positioning through decrease of illuminated bars. In bright sunlight, maximizing the visible shadow created by the solar panel is one means of determining the best position of the photovoltaic cell for maximum power output. The intuitive power display human interface device is particularly effective during overcast conditions when solar power is still available, but proper orientation is hindered by the lack of shadows. Additionally unseen shadows may be cast from trees, buildings, et cetera, which can drastically decrease the solar panel's output through shading of cells, within the module, from non-visible light (e.g. IR, UV).

Effects of environmental conditions on power supplies are not limited to solar panels. In the case of a thermoelectric generator, for example, the user may use the feedback from the intuitive power display human interface device to maximize the temperature difference of the system. This may be done by increasing the heat input, or decreasing the temperature of the heat-sink. The effectiveness of lithium-ion batteries is influenced by the local temperatures, particularly cold weather. Additionally, charge potential within the battery itself determines the ability of the unit to pass current to another device. Once the potential within the battery decreases to near zero, current will no longer be supplied to the desired devices, and the internal battery potential must therefore be established prior to continued use as a power supply.

Some USB devices, such as smart phones, are admittedly more sophisticated than others. Therefore, it is unsurprising that some devices have complicated charge controllers while others readily accept any available power. A prime example

of this is in smartphones, which determine the state of the power source when initially connected. These devices check the data pins of the USB source, and attempt to draw the recommended amount of current (e.g. 50 mA, 500 mA, 1000 mA). If the power is available, it will draw the suggested amount of current. If the source is power starved, and the device is unable to draw the suggested current, then charging may continue at a reduced current or not at all, as decided by the particular charge controller. This feature is meant to increase the lifetime on the device batteries.

However, these complicated charging methods can have undesired effects when using a power source with output which varies with time (e.g. solar panel, thermoelectric generator) because the power state of the source may only be determined when the device is connected to the source. Therefore, if the environment of the generator improves and more power is available than when the device was initially connected, the device will not charge at a faster rate until the 'bus' is cycled by disconnecting and reconnecting the USB device.

Furthermore, if the power flow into a device with such an advanced charge controller is temporarily impaired the device charging will decrease to a nominally lower current flow, and not return to the desired maximum until the device bus is cycled. This phenomenon can cause drastically increased charge times from alternative generators, particularly solar panels. For example, if a smartphone is charging at 1 A (5 W) from a portable solar charger, and an obstruction comes between the panel and the sun (such as a cloud, leaf, person), diminishing the solar flux on the panel, the current flow will decrease accordingly; however, once the obstruction moves and full solar intensity is restored to the panel, the smartphone will continue charging at the decreased current until the bus is cycled.

Overall the addition of an intuitive power display human interface substantially increases the user's knowledge and helps the user to have empirically derived understanding about the overall state of power transmission in the system it is used with and thereby can increase the overall usability of said power source. Because of the relative simplicity of the interface display and the highly intuitive nature of an additive interface display scheme, a large number of people with diverse cultures, languages, and educational levels will be able to fully utilize the power source it is used in conjunction with.

The present invention is, among other things, an intuitive means of displaying power. More specifically, the human interface device may be used with a standard connection to display instantaneous electrical power passing from an electrical supply to an electrical device. The display uses conceptual rather than explicit numeral depiction of the power such that an individual untrained with the intuitive power display human interface device (IPDHID) may easily interpret the amount of power, in a relative sense. The conceptual display of power without use of numbers may readily be achieved via a plurality of similar symbols of increasing size or brightness. An analogous display system is currently implemented globally to depict signal strength of wireless technologies.

Thermoelectric generators present a promising alternative to portable power-generation needs because of their ability to generate power under any scenario where a heating and cooling source is available. Thermoelectric generators harness the offset from equilibrium created by a temperature differential across dissimilar conductors, and convert this temperature difference directly into usable electrical power. The amount of electrical power generated by means of a



thermoelectric generator is proportional to the temperature difference across the dissimilar conductors.

Thomas J. Seebeck discovered thermoelectric power in 1821, and the conversion of temperature differences directly into electricity is appropriately known as the Seebeck effect. To realize a true thermoelectric device, both n-type and p-type materials are electrically coupled to complete a circuit. Jean-Charles Peltier discovered the presence of heat at an electrified junction of two dissimilar metals in 1834. The combination of the Seebeck and Peltier effects is known as the Thompson effect (after William Thomson-Lord Kelvin), who observed both phenomenon occurring simultaneously in 1851. By using these fundamental principles, thermoelectric devices can be created that, upon the application of power, cool from one side and emanate heat from the other; or, which generate power when one side of the device is cooled and the other side is simultaneously heated.

Bismuth telluride ( $\text{Bi}_2\text{Te}_3$ ) is one of the most common thermoelectric materials in use today due to its relatively high efficiency and material availability. Thermoelectric modules containing  $\text{Bi}_2\text{Te}_3$  may be purchased from a variety of manufacturers around the world. Bismuth telluride may be made p-type or n-type by introducing impurities of antimony or selenium, respectively. Bismuth telluride thermoelectric generation modules (TEGM) may comprise n-type and p-type doped legs which are electrically joined in pairs, each of which may generate  $\sim 150 \mu\text{V}$ . These pairs are then connected in electrical series to raise the voltage. The number of pairs of legs connected in the series determines the relative output voltage of the module at a given temperature differential. These modules may be connected in electrical series or parallel to form a thermoelectric generator system (TEGS). The output characteristics of the TEGS will follow the same general principals as just outlined for module assembly from thermoelectric legs.

The output characteristics of a given thermoelectric generator may be matched to the desired load for the TEGS. Many portable generators on the market today have standard output(s) such as USB or 12V auto/marine socket. Generally speaking, the closer the output voltage and current are matched to the requirements of the load, the less power will be lost during voltage regulation which is necessary to achieve stable standard output voltages such as 5V for USB and 12V for auto/marine. Voltage regulation is described in more depth elsewhere in the description of the invention.

Photovoltaic (PV) generators, or solar panels, have been used for portable and remote power generation for several decades. PV solar panels create DC electrical power directly from sunlight with no moving parts. Today, small solar panels ( $<100 \text{ W}$ ) come in many form factors and are widely used to power electronic devices such as cellphones, lights, batteries, laptops and more. With advances in technology and market size, PV generators have become economical for a global market. In highly developed economies, personal solar panels (1-10 W) have become particularly abundant in the outdoor activity and emergency preparedness markets for powering personal electronic devices including cameras, smartphones, MP3 players, radios and more. In developing economies, such as those found across most of the African continent, personal solar panels have become an integral part of society. In these developing nations personal solar panels often offer the sole source of electrical power, and are a main source of power for charging cell phones and other portable electronics. This allows the owner of personal solar panels not only to power the electronics of their home/family, but also to sell power from these personal solar panels to friends and neighbors, particularly for phone charging.

Solar panels are made of solar modules which are in-turn made of solar cells. Solar cells are semiconductors which produce electrical power when illuminated. Illumination causes electrons to be promoted from a lower energy band, within the solid, to a higher band, across a band-gap. When this electron, negatively charged, is promoted to a high band, a hole, or positive charge, is left in the lower band. This electron/hole pair is commonly known as an exciton. Excitons are separated within the solar cell through a built in potential, or voltage, which causes the flow of electrons toward to positive potential side, and the holes move oppositely toward the negative potential. The potential is built in to the surface of the solar cell through creating a P-N junction in the semiconducting material. By this means, electrical current, and therefore power, is created when the solar cell is attached to a load, completing a circuit. The amount current generated may depend on many variables, of which the amount of illumination, or solar/luminous flux, as well as the efficiency of the solar cell. The voltage is primarily dependent on the material of the cell, affecting the band-gap, as well as the construction of the modules and panel.

Solar cells are most commonly made of silicon, although there are many other semiconductor materials capable of producing solar cells including: Gallium Arsenide (GaAs), Cadmium Telluride (CdTe), Germanium (Ge), Copper Indium Gallium diSelenide (CIGS), and more. All of these materials have different band gaps, and therefore different output voltages from the solar cells. For example, the band gap of GaAs is 1.4 eV whereas the band-gap of Silicon is 1.1 eV. Several allotropes of silicon can be used for photovoltaic power generation, including monocrystalline Silicon (mono-Si), polycrystalline silicon (poly-Si), and amorphous Silicon (a-Si), all of which have slightly differing band-gaps due to differences in their crystalline structure.

It is also known that solar cells have nonlinear current versus voltage characteristics, because of the P-N junction creates a diode. Since electric power (P) is equal to the voltage (V) multiplied by the current (I),  $V \cdot I = P$ , and the output of a solar panel is nonlinear, there exists a maximum power point which is not at half the short circuit current or open circuit voltage. This power point can differ between solar cells, and is strongly affected by the quality of the P-N junction of the particular solar cell and available light.

Solar cells may be connected in series to form a module. This module will have output characteristics which depend on the quality, material, and number of cells. For example, for a silicon module with 6 cells in series the nominal open circuit voltage will be  $1.1\text{V} \cdot 6 = 6.6\text{V}$ . As the cells are connected in series, and the current through all cells must be the same, the current will be limited to that of the lowest output cell. These modules may be connected in electrical series or parallel to form an array. The output characteristics of the array will follow the same general principals as just outlined for module assembly from cells.

The output characteristics of a given solar panel may be matched to the desired load for the solar panel. Many solar panels on the market today have standard output(s) such as USB or 12V auto/marine socket. Generally speaking, the closer the output voltage and current are matched to the requirements of the load, the less power will be lost during voltage regulation which is necessary to achieve stable standard output. Voltage regulation is described in more depth elsewhere in the description of the invention.

Electrical power storage through means of an electrochemical cell, or battery, is one of the oldest methods of electrical power. Battery chemistries include lithium/carbon,



nickel metal hydride, nickel cadmium, zinc air, lead acid, and more. These batteries power personal electronics, automobile starters, and more.

Each battery chemistry has its particular cell potential, or voltage, which changes depending on charge state of the battery. Several cells may be combined in series or parallel to achieve the desired output voltage and current. For example, a lead acid battery has a cell voltage of 2.1 V whereas lithium-ion batteries have a typical cell voltage of 3.7 V, depending on the cathode material. Standard auto/marine batteries, (12 V auto/marine cigarette socket standard connection), use 6 lead acid cells in series, for a nominal voltage of 12.6 V ( $6 \times 2.1 \text{ V} = 12.6 \text{ V}$ ). Each battery chemistry may have its particular advantage or disadvantage for a given application. Characteristics which may vary between cell chemistries include: cell voltage, maximum charge/discharge currents, environmental concerns such as toxins and acids, energy density, cost, and many more.

In the previous decade, lithium based batteries have seen a particular increase in production and market penetration. This increase in lithium batteries is primarily due to the high energy storage density allowing lithium batteries to accommodate the increasingly small size of electronic devices. This high energy density comes from the small size and weight of the lithium ion, and the relatively large cell potential of  $\sim 3.7 \text{ V}$ . Additionally, with a cell potential of 3.7 V, a single cell lithium battery integrates well with the USB standard of 5V. Single cell lithium batteries may fully charge from a USB port since 5 V is higher than 3.7 V. It is important to regulate the charging of a battery, so as not to surpass charging current/voltage limits which may damage or destroy the battery. These charge controllers are commonly built either into the device or into the battery.

The output characteristics of a given battery may be matched to the desired load for the battery pack. Many battery packs on the market today have standard output(s) such as USB or 12V auto/marine socket. Generally speaking, the closer the output voltage and current are matched to the requirements of the load, the less power will be lost during the voltage regulation necessary to achieve stable standard output. Voltage regulation is described in more depth elsewhere in the description of the invention.

Voltage regulation circuits are commonly used in electronic devices, and are readily available on the market. For example, any electronic device with a battery will have a regulation circuit for the battery in order to provide the correct charging voltage, prevent over charging, and more. Additionally, battery powered devices often have voltage regulators on the output of the battery in order to provide the electronics within the device the correct and stable voltage. Those skilled in the art know there are many methods of regulating voltages, which may be as simple as a resistor or complicated as high frequency switching circuits.

There are three general types of voltage regulators: those which increase (boost) a lower voltage to a higher voltage, those which decrease (buck) a higher voltage to a lower voltage, and those which can both buck and boost an input voltage to given output voltage. Within these three categories many topologies of circuits may exist, such as: SEPIC, CUK, Split-Pi, linear, and more.

Voltage regulators are ubiquitous in mobile charging systems, because there are so many personal devices which charge from standard outputs, such as 5V USB and 12V auto/marine. When designing a mobile charging system, one or more of the above regulators may be required depending on the power source and the device being powered. For example, a thermoelectric generator may require a buck/

boost regulator. The output voltage from the TEGS may be above the desired user voltage when the TEGS starts operation, and as time progresses the TEGS output voltage decreases below the desired user voltage as the temperature differential decreases. On the other hand, solar panels may use a buck regulator, since the output voltage of the array is always higher than the desired user voltage. However, boost regulators are used in a portable single cell lithium battery pack for charging USB devices to take the voltage of the lithium cell (3.7V) to the 5V required for the USB standard.

The presence of mobile communication technology in the form of cellular phones and “smart” phones has grown rapidly over the past 2 decades, and is now believed to have a global market penetration of nearly 90%, equaling over 6 billion users. Recently, as well as in the foreseeable future, the most growth is from developing economies such as India and much of Africa, where limited access to an electrical grid exists. In these regions infrastructure development has been unable to keep up with population growth/movement, and vital tasks, such as personal banking, are performed using cellular phones. Due to the enormous size of the cellphone/smartphone market, it is unsurprising that there exist many manufacturers of these devices including Apple, Samsung, Nokia, HTC, LG, ZTE, Motorola, Huawei and more.

Though operating principles between different makes of mobile phones are generally similar, the hardware interface for charging the internal battery remains largely proprietary to specific makes/brands. For example, Apple currently uses an eight pin “lightning” connector for its mobile technology, while the major market competitor, Android, charge primarily from the 5 pin USB-micro connector. Both of these connector types are built for the USB 2.0 standard, meaning both operate at 5 Volts and 0-1 Amps; however they are physically incompatible with one another’s devices. Similarly, Nokia, Motorola and Samsung may all use different charging connector than the two previous examples.

Moreover, the voltage on the data pins of the USB connector, which a charging cable may be plugged into, may affect the charging rate of the connected device. For example, with Apple devices it is customary to for USB-pin-2 to be 2.65 V and USB-pin-3 to be 2.05 V on the source to enable 1 A charging, else the device may charge at decreased rate such as 500 mA. However, with Android devices charging from USB-micro connectors, it is customary to short USB-pin-2 to USB-pin-3 to enable 1 A charging, else the device may charge at decreased rate such as 500 mA. Other USB devices may have different requirements of the source data pin voltages to enable fast charging of the device.

Universal Serial Bus or USB may not be as universal as the name implies, because of the vast number of devices with their differing charging standards as described above. Though all the described devices may charge from the same given USB port, differing charging results for each device may be experienced by end user, often unknowingly. The described invention allows the end user to know the amount of power being transferred into their device while charging from a universal port, through an intuitive LED based display. This allows the user to troubleshoot charging problems, and may help achieve the most desired charging results.

As seen in FIG. 1, the intuitive power display human interface device 1 comprises a power sensor 2, a logical interface controller 3, and an interface output device 4. The power meter operates by measuring the flow of current from power source 5, using power sensor 2, into device(s) being



powered 6. The human interface output device 4 may comprise a plurality of individually electrically addressed human interface output devices 8 controlled by electronic switches 7 in the logical interface controller 3.

According to one embodiment, electrical power from the power source 5 enters the IPDHID 1 through an electrical connection 9 and continues to the power sensor 2. The power sensor 2 supplies the logic controller 3 with a reference signal 11. This reference signal 11 conveys the power flow from the source 5 to the device 6 to the user of the system 1 by means of the interface output device 4. The amount of power flowing from the source 5 to the device 6 through the IPDHID 1 may be discreetly displayed 8 in the human interface output 4 by use of the logic controller 3. The logic controller 3 receives the reference signal 11 from the power sensor 2. The logic controller 3 then outputs discrete signals 7 to the discrete components 8 of the human interface display 4. When the amount of power flowing from the source 5 to the device 6 through the system 1 varies, the reference signal 11 also varies in similar proportion to the change of power flow from 5 to 6 and in-turn the change in power flow is shown to the user of system 1 through a change in discretely illuminated parts 8 of the human display 4.

When implemented by an individual skilled in the art, the system 1 consumes orders of magnitude less power than is being supplied from the source 5 to the device 6. This is due to the fact that power sensors 2, logic controls 3 and methods of displaying discrete power 8 are increasingly efficient, and operate with only milliwatts of power. Therefore, when properly designed, the power diverted 13 to operate the logic controller 3 and display 4 is much less than the power supplied 14a from the source 5. This being said, the power 14a from the source 5 entering the system 1 through the electrical connection 9 is approximately (within 1%) equal to the power 14b leaving the system 1 through the electrical connection 15 to the device 6. In order to preserve the flow of electrical current the power source 5 the IPDHID system 1 and the device 6 share a common ground 12.

In a potential embodiment, it may be desirable to include a switch 42 to interrupt the power 14b leaving the system 1 into the device 6. The switch 42 may be controlled by the same logic controller 3 as is used to control the display elements 8, by means of a signal 43. Such a method may result in small additional cost of the IPDHID 1 for the additional functionality. When activated, the switch 42 effectively disconnects the device 6 by interrupting the power 14b being supplied to the device 6. After the power 14b is interrupted for some amount of time (e.g. 0.5-5 seconds) the controller 3 again sends a signal 43 to the switch 42 which reestablishes the flow of power 14b from the source 5 to the device 6 through the IPDHID 1. In this way, the system 1 may effectively cycle or reset the 'bus' of the device 6 automatically, without the need of user intervention to physically disconnect the device 6 from the source 5 or IPDHID 1. The conditions which will cause the activation of the switch 42 may be programmed into the logic controller 3. The addition of an automatic bus cycling feature may be particularly desirable when using a nonstandard power source 5 such as a portable solar panel, as earlier described.

The intuitive power display human interface device 1 may be very physically minute. This is due to the operational simplicity of the system and the wide commercial availability of extremely small package sizes of microelectronic controllers suitable for use as the logical interface controller 3. For example, one such device is only 2 mm by 2 mm. The

low physical extent in volume and footprint as well as the operational simplicity and small part count allow for production of system 1 at low economic cost. In a potential embodiment, system 1 may be embedded in a wide variety of power generation systems 5 or power transmission systems without significantly increasing the size or cost in contrast with comparable a cable or system without the system 1.

FIG. 2 shows an embodiment of the system 1 using a thermoelectric generator (TEG) 49 as the power source 5, seen in FIG. 1, to power the device(s) 6. The TEG 49 creates power proportional to the applied temperature differential, and may require a voltage regulator 48 to properly power the device 6. Power may be supplied 14a to the power sensor 2 and logic controller 3 via an electrical connection 9. All parts of the system 1 may share a common ground 12 as well as TEG 49 and device 6. In proportion to how much power is being transferred from the TEG 49 to the device 6, a signal 11 may be sent from the power sensor 2 to the logic controller 3 which may in turn send signals 7a,b,c,d,e activating the corresponding discretely illuminated parts 8a,b,c,d,e of the display 4. The logic controller 3 may also send a signal 43 to a switch 42 to interrupt the power flow 14b to the electrical connection 15 and the device 6. The logic controller 3 may again send a signal 43 to a switch 42 reestablishing the power flow 14b to the electrical connection 15 and the device 6. This action affectively cycles the bus power of the device 6, which may be required due to power output fluctuations of the TEG 49. The voltage regulator 48 may be built into system 1 with an internal electrical connection 9 which may be made by means of solder and PCB traces. Conversely, the voltage regulator 48 may already be present with the TEG 49.

FIG. 3 shows another embodiment of the system 1 using a photovoltaic (PV) generator 50 as the power source 5, seen in FIG. 1, to power the device(s) 6. The PV generator 50 creates power proportional to amount of luminous flux, and may require a voltage regulator 48 to properly power the device 6. Power may be supplied 14a to the power sensor 2 and logic controller 3 via an electrical connection 9. All parts of the system 1 may share a common ground 12 as well as PV generator 50 and device 6. In proportion to how much power is being transferred from the PV generator 50 to the device 6, a signal 11 may be sent from the power sensor 2 to the logic controller 3 which may in turn send signals 7a,b,c,d,e to activate the corresponding discretely illuminated parts 8a,b,c,d,e of the display 4. The logic controller 3 may also send a signal 43 to a switch 42 which interrupts the power flow 14b to the electrical connection 15 and the device 6. The logic controller 3 may again send a signal 43 to a switch 42 reestablishing the power flow 14b to the electrical connection 15 and the device 6. This action affectively cycles the bus of the device 6, which may be required due to power output fluctuations of the PV generator 50. The voltage regulator 48 may be built into system 1 with an internal electrical connection 9 which may be made by means of solder and PCB traces. Conversely, the voltage regulator 48 may already be present with the PV generator 50.

FIG. 4 shows another embodiment of the system 1 using electrochemical storage 51 as the power source 5, seen in FIG. 1, to power the device(s) 6. The electrochemical storage 51 creates power proportional to electrochemical potential, and may require a voltage regulator 48 to properly power the device 6. Power may be supplied 14a to the power sensor 2 and logic controller 3 via an electrical connection 9. All parts of the system 1 may share a common ground 12



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as well as electrochemical storage 51 and device 6. In proportion to how much power is being transferred from the electrochemical storage 51 to the device 6, a signal 11 may be sent from the power sensor 2 to the logic controller 3 which will in turn send signals 7a,b,c,d,e to activate the corresponding discretely illuminated parts 8a,b,c,d,e of the display 4. The logic controller 3 may also send a signal 43 to a switch 42 which interrupts the power flow 14b to the electrical connection 15 and the device 6. The logic controller 3 may again send a signal 43 to a switch 42 reestablishing the power flow 14b to the electrical connection 15 and the device 6. This action affectively cycles the bus of the device 6, which may be required due to power output fluctuations of the electrochemical storage 51. The voltage regulator 48 may be built into system 1 as part the electrochemical storage device 51 with an internal electrical connection 9 which may be made by means of solder and PCB traces. Conversely, the voltage regulator 48 may already be present within the electrochemical storage 51.

FIG. 5 shows another embodiment of the system 1. In this embodiment the IPDHID system 1 is a discrete unit placed in-line between the power source 5 and the device being powered 6. In the described embodiment, the power source 5 connects to the system 1 through a standard USB A male receptacle 9 mounted to the printed circuit board (PCB) 10. Through the PCB 10 the power source 5 connects to the device 6 by means of the USB A female receptacle 15. Also connected to the PCB 10 may be the power sensor 2, the logical device 3, and the light emitting devices 16. Through the PCB 10 the power sensor 1 relays the reference signal 11 to the logic device 3. In-turn the logic device 3 relays discrete signals 7 to the discrete light emitters 16 illuminating the discrete power display 8 of the human interface 4 in proportion to the power flow from the source 5 to the device 6, as shown in FIG. 1.

The embodiment of system 1 as shown in FIG. 5 allows the user to know the approximate amount of power being transferred from the USB power source 5 to the USB device 6 through the power discrete display 8 of the human interface 4. In this embodiment, the power discrete display 8 is segmented into five discretely illuminated units with corresponding power amounts set by the programming of the logic device 3. For the described embodiment, intuitive power display increments 8 may correspond to either 1 watt or 2 watts of electrical power passing from the power USB source 5 to the USB device 6 through the system 1, depending on whether the logic controller 3 is programmed for USB 2.0 (1 A\*5V=5 W/5 increment=1 W/increment) or USB 3.0 (2 A\*5V=10 W/5 increment=2 W/increment) respectively.

FIG. 6 shows another potential embodiment of the system 1, which uses a TEG 49 as the power source 5. In this embodiment, a voltage regulator 48 for the TEG 49 has been built in to the system 1. The power from the TEG 49 may be necessarily regulated to 5V by the voltage regulator 48 for the standard USB output connection 15. The amount of power transferred from the TEG 49 out the electrical connection 15 may be displayed via discrete LED lights 8a,b,c,d,e.

FIG. 7 depicts another potential embodiment in which the IPDHID 1 is built into a PV generation 50 system with a 5V USB output connection 15. The human interface display 4 may be made of discrete illumination elements 8a,b,c,d,e which give user feedback on how much power is being transferred from the PV generators 50 out of the electrical connection 15.

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Shown in FIG. 8 is another embodiment of the IPDHID 1 which is built in with an electrochemical storage device 51. A human interface display 4 may display the amount of power being transferred from the electrochemical storage device 51 to the device 6 being powered. FIG. 8a shows a top down view of one embodiment of an electrochemical storage device 51 with a human interface display 4 comprised of discrete illumination elements 8a,b,c,d,e. The electrical input connection 9 and output connection 15 is not visible from this projection, and may be located on a side of the electrochemical storage device 51. FIG. 8b shows a front on view of another embodiment of an electrochemical storage device 51 with a human interface display 4 comprised of discrete illumination elements 8a,b,c,d,e. In this embodiment, the human interface display 4 may be located directly above a 5V USB connection 15. Also visible in FIG. 8b is an electrical input connection 9, which may be a 5V USB-micro.

FIG. 9 illustrates another embodiment of the IPDHID 1 which has been built into cable with a standard input connection 9 and 3 different output connection 15 types. FIG. 9a depicts the IPDHID 1 with discrete illumination parts 8a,b,c,d,e built into the end with the standard input connection 9 and three example output connections 15. FIG. 9b depicts the IPDHID 1 with discrete illumination parts 8a,b,c,d,e built into the middle of a cable with a standard input connection 9 and three example output connections 15. FIG. 9c depicts the IPDHID 1 with discrete illumination parts 8a,b,c,d,e into three examples of output connections 15 of a cable with a standard input connection 9.

FIG. 10 is a detailed circuit diagram of a potential embodiment as similarly described in FIGS. 1-9. The power and/or data enters the system 1 by means of the external connector 9, which in the described embodiment is a Male USB A connector 17 consisting of 4 pins 14, 19, 20, 12 and a cover shield connection 21. Electrical power is transmitted via the Male USB A connector 17 to the PCB 10 and the electrical circuits contained therein through pins 14 and 12 respectively. Data which may come from the source 5 is passed through to PCB 10 to the device 6 through the female USB A connector 18 along data connections 19 and 20 without alteration. In this embodiment of the invention, after power passes into the circuits of the PCB 10 a relatively small amount of power from 14a is drawn through 13 to power the interface display 4, power sensor 2, and logic controller 3. In this embodiment, functions of power measurement 2 and logical control 3 sub-systems of 1 are fulfilled by two microelectronic packages: a micro-current-sense amplifier 24 is used to accurately measure current making it analogous to the power sensor 2, and a programmable logic controller 25 which both calculates power from the measured current and may be programmed to appropriately control the human interface output display 4. In actuality the small amount of current, and therefore power, drawn through 13 is connected to 24 and 25 in parallel with power stabilizing and noise filtering capacitors 30.

Current flowing from 17 to 18 via 14a flows through a small (0.0200 Ohms) accurately known (+/-0.1%) electrical resistor 26 en-route to 14b. The voltage developed across the resistor 26 may be measured by the integrated circuit 24 using the input measurement pins 22 and 23. Capacitors 27 and 28 are coupled in parallel to circuit segments 14a and 14b respectively to stabilize the electrical character, namely voltage across 26. The voltage measured across the resistor 26 is amplified by 24 and transmitted to the programmable microcontroller 25 via 11. The program stored in the microcontroller 25 calculates the current flowing through the



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resistor 26 from the voltage signal from 24 and because it is itself connected to 14 via 13 as well as to the ground electrical network 12 it can also measure the voltage between 14 and 12. With both voltage and power measured, the microcontroller 25 can calculate a value for instantaneous power transmission from 17 to 18 using the relationship  $\text{Power} = \text{Voltage} \times \text{Current}$ . The programmable microcontroller 25 illuminates elements 8 of the human interface display 4 using illumination producers 16 that may be discretely addressed using the general purpose analog outputs 7 of the logical control device 3, in this embodiment the microcontroller 25. The power consumption of the illumination producers 16 are limited by electrical resistors 29. The brightness of the illumination producers 16 can be adjusted down from the maximum rated brightness by increasing the value of 29. The program of the microcontroller 25 in the above described embodiment illuminates display segments 8 of the human interface display 4 in congruence with the conceptual display of power symbols of increasing size. In the case where the power measured from 17 to 18 is greater than zero (0.1 W) but less than 1.4 W the microcontroller 25 may close the circuit from 7a through illumination provider 16a and human interface display 4 element 8a will be illuminated. In the case where the power measured from 17 to 18 is between 1.5 W and 2.5 W the microcontroller 25 may close the circuit elements 7a and 7b through illumination providers 16a and 16b and human interface display 4 elements 8a and 8b will be illuminated. In the case where the power measured from 17 to 18 is between 2.5 W and 3.5 W the microcontroller 25 may close the circuit elements 7a,b,c through illumination providers 16a,b,c and human interface display 4 elements 8a,b,c will be illuminated. In the case where the power measured from 17 to 18 is between 3.5 W and 4.5 W the microcontroller 25 may close the circuit elements 7a,b,c,d through illumination providers 16a,b,c,d and human interface display 4 elements 8a,b,c,d will be illuminated. In the case where the power measured from 17 to 18 is greater than 4.5 W the microcontroller 25 will close the circuit elements 7a,b,c,d,e through illumination providers 16a,b,c,d,e and human interface display 4 elements 8a,b,c,d,e will be illuminated.

The switch 42 is comprised of a number of elements which use the signal 43 from the logic controller's 3 output 7g to interrupt or establish power flow 14b from the source 5 to the device 6 through the IPDHID 1. One component is a p-channel field effect transistor (PFET) 44, which are widely available on the market. Those skilled in the art will note that the use of PFETs may be preferable because the native state of this device normally allows conduction between source and drain without requiring a signal, analogous to a normally on momentary mechanical switch. To construct the switch 42 with a PFET 44, supporting components such as a stabilizing and decoupling capacitor 45 and voltage divider resistors 46, 47 may be necessary. The stabilizing capacitor 45 stabilizes the power flow through the PFET 44 and electrically decouples the gate input from the source, protecting the PFET 44 and adding to the overall reliability of the system 1. The voltage divider may be comprised of resistors 46 and 47 to provide the necessary voltage to flip the internal field within the PFET 44 from the signal 43 which determines whether the switch 42 is on or off.

Additional switches 52 and 53 may be used to control the data lines 19, 20 of the USB connections 9, 15 and may function similarly to switch 42. The microcontroller 25 can provide signals 54, 55 from general purpose analog outputs 7h, 7j which activate/deactivate the switches 52, 53 respec-

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tively. Switches 52 and 53 may be comprised of a PFET 44, supporting components such as a stabilizing and decoupling capacitor 45 and voltage divider resistors 46, 47.

If switch 52 is activated, the data line 19 is broken and the input 19 to the switch 52 differs from the output 56. The microcontroller 25 may provide a signal 57 from output 7i which can be electrically connected the output 56 of switch 52. These two signals may be DC voltages, which will follow Kirchhoff's laws when combined. The resulting signal 58 may exit the system 1 through the output connector 15 to communicate with the device 6.

Similarly, if switch 53 is activated, the data line 20 is broken and the input 20 to the switch 53 differs from the output 59. The microcontroller 25 may provide a signal 60 from output 7k which can be electrically connected the output 59 of switch 53. These two signals 59, 60 may be DC voltages, which will follow Kirchhoff's laws when combined. The resulting signal 61 may exit the system 1 through the output connector 15 to communicate with the device 6.

A user actuated switch 62 may be included as part of the IPDHID 1. This user actuated switch 62 may comprise simple mechanically actuated electrical connections 63 as well known and commonly implemented by those skilled in the art. When 62 is actuated the switch 63 may be connected to ground 12 which effectively sends a signal 64 to the input 7m of the microcontroller 25. This signal 7m from user switch 62 may then use the microcontroller 25 to activate or deactivate switches 52 and 53, which in turn may change the continuity of the data lines 19 and 20.

In the case when the IPDHID 1 is implemented as an embedded part of a larger system, the logical controller 25 may need more information about the power available from the power source before the voltage is regulated. An optional electrical connection 74 may be made directly to the output of the power source and give greater information about the state of the source. This may be advantageous because in many cases the output voltage of a power source is directly proportional to the amount of power available. Greater information allows the logical controller 25 to be programmed to cycle the bus power using switch 42 at appropriate times such as when a larger amount of power becomes available or to not cycle it when it will make no difference in the ultimate power drawn. The power source voltage signal 75 may be created by creating an electrical circuit to the voltage output of the power source external to the electrical connection 74 and to divide the power source voltage across a known resistor network 76. The logical controller reads the signal 75 from the electrical connection and voltage divider of 74 and according to its program, cycles the bus power from 14a to 14b appropriately.

FIG. 11 shows the arrangement of electrical pathways in USB junctions. The most common type of USB A (host side) 70 connector contains the 4 electrical connections that transmit power on the +5 Volt 68 and ground 65 and that carry data on the D+ 66 and D- 67 lines. Client Device sides of the connection USB B 71 typically contain an ID pin 69 that is used by the device to detect if a host is present or not. Those skilled in the art will know that USB data host devices and dedicated USB chargers deal with the distribution of power in quite different ways. USB is both a power distribution standard and data link. In the case where a data link is established between a client and a host over USB, the host device will dictate to the client device how much power may be drawn. The client device may negotiate with the host for more power but in many cases this requires installation of specialized and proprietary drivers on the host device. Dedicated USB charging ports such as those that convert



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household alternating current into 5 Volt direct current act as current limited sources to any USB device connected with the maximum power available as a limitation of the host USB charger. Some manufacturers have created their own standard to inform the device connected to a dedicated USB how much power is allowed to safely be drawn; typically this is based on a much simpler signal than serial bus communication. There are several internationally agreed upon standards and there are many manufacturer specific specifications. For example the USB B side (client device) of a USB mini-B 71 contains the 4 electrical connections that transmit power on the +5 Volt 68 and ground 65 and that carry data on the D+ 66 and D- 67 lines. A common method to indicate to a client device using the USB mini port 71 that it is connected to a dedicated charger port is to implement an electrical resistance of ~200 Ohms between D+ 66 and D- 67. Whereas the D+ 66 and D- 67 of a USB B micro connector are typically shorted with an electrical resistance of less than 1 Ohm between D+ 66 and D- 67. Other manufacturers use a proprietary connector with many pins. The added pins enhance functionality; however standard USB pins may also be contained within such Dock Connectors 73. This type of connector may also be used in conjunction with a cable that allows the device to be used with standard host side connections such as USB A 70 and transmit the 4 electrical connections that transmit power on the +5 Volt 68 and ground 65 and that carry data on the D+ 66 and D- 67 lines. Do to the very large number of accessories and the length of time that dock connectors 73 have been in use, proprietary standards have developed to allow the large number of devices with different power requirements to interact in the same accessory ecosystem without great risk of harm do to the use of incompatible devices. For example connection of a device that requires 2 A of current to a host charger that can only supply 500 mA of current could result in damage to the host charger. Those skilled in the art will note that simply providing a charger for all devices that can supply the maximum requirement of any device in the ecosystem is not economically viable as a device that needs only 500 mA at 5V will have an electrically simpler and less expensive host charger associated with it. Those skilled in the art familiar with the Dock Connector 73 know that the voltages output to the pins D+ 66 and D- 67 control the maximum current draw of devices using the Dock Connector 73. In the case where a host using the Dock Connector 73 can only provide 500 mA at 5V the D+ 66 and D- 67 will both be set at 2.0V informing the client device of the max charge specification of the host. In the case where a host using the Dock Connector 73 can only provide up to 1000 mA at 5V the D+ 66 and D- 67 will be set at 2.0V and 2.8V respectively informing the client device of the max charge specification of the host. In the case where a host connecting to a client device via the Dock Connector 73 can provide up to 2000 mA at 5V the D+ 66 and D- 67 will be set at 2.8V and 2.0V respectively informing the client device of the max charge specification of the host.

FIG. 12 shows possible embodiments of the intuitive human output display 4 through plausible methods of intuitive discrete display parts 8. The display 4 may implement many means of communicating the amount of power flowing through the system 1 through variations of the discrete methods of display 8. The discrete display units 8 are illuminated via the lighting components 16 in accordance to the amount of power transferring from the power source 5 to through the system 1 to the device 6 as previously described. The display 4 may implement many means of communicating the amount of power flowing through the system 1

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through variations of the discrete methods of display 8 as illustrated in FIG. 12a, FIG. 12b, FIG. 12c, and FIG. 12d.

Shown in FIG. 12a is one embodiment of the human interface display 4 in which varying amounts of power 31, 32a, 32b, 32c, 32d, 32e are displayed through the discrete output units 8a, 8b, 8c, 8d, 8e. Reference number 31 corresponds to a voltage being detected from the source 5 with zero power transferring to the device 6 indicated by discretely illuminating 8a red. When the power sensor 2 detects power less than one watt transferring from source 5 to device 6 through system 1, the amount of power 32 is displayed through green illumination of unit 8a of the output interface 4. If FIG. 12a. represents the display 4 for a USB 2.0 device 6, increasing increments of power transference 32a, 32b, 32c, 32d, 32e from the source 5 to the device 6 of single watts of power until the maximum of 5 W can be described by the further green illumination of 8a, 8b, 8c, 8d, 8e.

Illumination colors of the discrete elements 8 in the output display 4 may vary in accordance with varying applications. For example, if the system 1 is an integrated part of a solar power generation system 5 the elements 8 may be illuminated blue, as seen in FIG. 12b, for increased visibility of the display 4 in direct sunlight. However, green may be preferred to blue due to its lower cost per unit in production. Alternately, varying colors of 8 may signify different power increments 31, 32a, 32b, 32c, 32d, 32e in comparison to different embodiment of similar systems 1. Such may be the case in the instance where green illumination, FIG. 12a, is used for USB 2.0 devices 6; whereas blue illumination, FIG. 12b, is used for USB 3.0 devices 6. In this scenario the power increments 32a, 32b, 32c, 32d, 32e would correspond to 1 W, 2 W, 3 W, 4 W, 5 W, and 2 W, 4 W, 6 W, 8 W, 10 W for USB 2.0 and USB 3.0 respectively.

The shape and relative sizes of the discrete elements 8 of the output display 4 may be varied between differing embodiments of the system 1 and remain in the spirit of the current invention. As the purpose of the system 1 is to convey the amount power transference from the source 5 to the device 6 by means of the output display 4 to a human user, the discrete display elements 8 are shown in FIG. 12a and FIG. 12b are rectangular bars of increasing size, in a similar fashion to internationally used wireless signal strength displays, in which illumination of increasing size discrete display bars 8a, 8b, 8c, 8d, 8e correspond to increasing amounts of power 32a, 32b, 32c, 32d, 32e. However, taking production costs under consideration, it may be advantageous for the discrete elements 8 to all consist of the same part as seen in FIG. 12c, as this decreases cost of production of the output display 4 and ultimately the system 1.

As shown in FIG. 12d, an alternate method using discrete display elements 8 in the human interface display 4 of another potential embodiment of system 1 may be desirable. In this potential embodiment the power display 4 comprises a matrix of discrete elements 8. In this instance, the amount of power 32 on the display 4 of the system 1 may correspond to increasing illumination of components 8 determined by the index of the matrix 8ij. Consider, for example, if FIG. 12d represents a 10 W display 4, when system 1 shows 8 watts 32h of power passing from the source 5 to the device 6, all discrete lighting elements 8 will be illuminated with indices corresponding to 8a through 8h and 8-1 through 8-8, or 8-1a through 8-8h.

The present invention utilizes the thermoelectric effect to generate electricity. More specifically, the temperature difference imposed across a thermoelectric element creates a



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voltage due to the differences in diffusivity and phonon drag imposed upon the n-type and p-type carriers within the thermoelectric element. Under the second law of thermodynamics, from statistical mechanics interpretation, the thermoelectric power of a material can also be defined as the entropy per charge carrier. The present invention harnesses the entropy created by the temperature differential imposed by the system, and transforms this entropy (heat) into electrical power.

The efficiency by which a thermoelectric element converts heat into electricity is quantified by the dimensionless figure of merit (ZT), defined as  $ZT = S^2 \cdot T \cdot \sigma / k$ . Here, T is the average temperature between the hot and cold sides, S is the Seebeck coefficient,  $\sigma$  is the electrical conductivity, and k is the thermal conductivity. The figure of merit for a given material varies as a function of temperature, performing best at temperatures where ZT is maximized.

Bismuth telluride ( $\text{Bi}_2\text{Te}_3$ ) is one of the most common and least expensive thermoelectric materials in use today. Thermoelectric modules containing  $\text{Bi}_2\text{Te}_3$  may be purchased from a variety of manufacturers across the globe. Bismuth telluride may be made p-type or n-type by introducing impurities of antimony or selenium, respectively. The present invention may utilize thermoelectric material comprising bismuth telluride, as the temperature of the hot (about 300° C.) and cold (about 100° C.) sides of the present invention coincides well with the temperature range in which ZT for bismuth telluride is maximized.

Bismuth telluride thermoelectric generation modules (TEGM) may comprise n-type and p-type doped legs which are electrically joined in pairs. These pairs are then connected in electrical series to raise the voltage. The number of pairs of legs connected in the series determines the relative output voltage of the module at a given temperature differential. Bismuth telluride thermoelectric legs are most commonly coupled using copper interconnects. These coupled pairs in series are encapsulated between two parallel insulating plates. Such plates are commonly made of alumina. TEGM are commercially available today from a variety of sources. The number of TEGM electrically connected within the system influences the electrical power output, and the size, shape, materials, and number of junctions within a given TEGM may be varied from application to application.

FIG. 13 shows one embodiment of a lightweight thermoelectric power generator system 101 in accordance with the teachings of the current invention. The system 101 includes a vessel 102 that may be placed upon a heat source 104. The heat source 104 may be a flame from a petroleum, alcohol, biomass, or another combustible fuel source, or the vessel 102 may be heated by other means, such as solar mirrors focused upon a bottom of the pot. The power generated by the thermoelectric generator system 101 may be routed through an internal high-temperature-resistant wire 105a into a temperature resistant wire conduit 106, and then to a temperature resistant connector 107 using a high-temperature-resistant wire 105.

The vessel 102 may be lightweight, have a handle 103, and may be designed to retain and heat a phase change material such as water. The handle 103, in addition to being used in the typical manner to hold and relocate the vessel 102, may also be used to hold the high-temperature-resistant connecting wire 105 at an increased distance from the heat source 104. This is achieved by routing the high-temperature-resistant wire 105 and the connector 107 through the handle 103 during normal operation of the system 101.

A power regulation assembly 108 is electrically coupled to the generation system 101 through the connector 107. In

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a particular embodiment, the power regulation assembly 108 incorporates the Power Display Human Interface device of FIG. 1-3, as detailed in FIG. 1-12 in this embodiment the Power Display Human Interface Device is incorporated within DC to DC regulation circuit 109a. The temperature-resistant wire 105 leads away from the heat source 104 into an environmentally hardened circuit enclosure 109, and connects to a DC to DC voltage regulation circuit 109a. The DC to DC voltage regulation circuit 109a provides regulated voltage through a standard connector 110 to a mobile device 111, such as a cellular phone.

FIG. 14 illustrates an exploded view of the lightweight thermoelectric generator system 101 comprising the vessel 102 to which the TEGM 112 are affixed. A plurality of spacers 113 of a height (0.010") slightly greater than the height of the TEGM 112 span the gap between the vessel 102 and bottom plate 114 (see FIG. 3). A bottom plate 114 is secured to the vessel 102 using fasteners 115, such as rivets or screws, which pass through the spacers 113. In an alternative embodiment, bottom plate 114 is attached to the vessel by spot-welding the spacers to vessel and bottom plate to spacers. The spacers 113 maintain a gap between the vessel 102 and the bottom plate 114. The TEGM 112 are situated within this gap.

In order to prevent damage to the TEGM 112 from water, combustion byproducts, and other debris, this gap is sealed around the circumference of the bottom of the vessel 102 with a high-temperature gasket 118 (see FIGS. 2, 3). A thermal interface enhancer 116 is tape cast on both sides of the TEGM 112 in order to maintain intimate thermal contact between the TEGM 112, the vessel 102, and the bottom plate 114. Thermal interface inhibitors 117 are placed between the vessel 102 and the plurality of spacers 113, and help achieve a higher temperature differential across the TEGM 112, as discussed in more detail below.

Using the high temperature conduit 106, the wire 105 is guided out of the bottom of the system 101 towards the rim of the vessel 102 along the handle 103. All or part of the conduit 106 may be secured to, and be in intimate thermal contact with the vessel 102, so as to limit the temperature within the conduit 106. The high-temperature wire 105 may comprise two multi-strand copper conductor wires of gauge adequate for handling the power output of the system 101. The wire 105 conducts the electrical power from the TEGM 112 to the regulation assembly 108, and ultimately provides power to the mobile device 111 using the standard connector 110. A plurality of devices 111 may be powered by the system 102, with the voltage being set by the regulation circuit 109a. Examples of such devices 111 include single cell lithium ion batteries in mobile devices that are typically charged using a 5V supply, and appliances commonly used in cars and RVs requiring a 112V supply, such as lights and fans, or two cell lithium ion devices. A currently preferred embodiment utilizes standard connectors 110 such as USB or US AUTO/MARINE sockets for outputs of 5V and 112V respectively, though the output voltage can be adjusted through the regulation circuit 109a to provide power to (or charge) a wide variety of low power devices that use nonstandard voltages.

In a currently preferred embodiment of the system 101, the vessel 102 is stamped from a thin (0.0390") sheet of aluminum. Aluminum may be an exemplary material for the vessel 102 due to its high thermal conductivity (~250 W/mK), low density (2.7 g/cc), ease of formation, corrosion resistance, and low cost. The superior thermal conductivity allows for rapid dissipation of the heat from the TEGM 112, correspondingly creating an ultimately lower cold side tem-



perature during operation of the system **101**. Stainless steel, which is the most common material used to form vessels for boiling water, may also be employed to form the vessel **102**. However, it is noted that the thermal conductivity of aluminum is more than ten times greater the thermal conductivity of stainless steel ( $\sim 19$  W/mK), and that the density of aluminum is about three times less than the density of stainless steel (7.9 g/cc). The use of aluminum to form the vessel **102**, hence, may provide the system **101** with increased efficiency, portability, and profitability. Additionally, the surface of the aluminum vessel **102** may be hard anodized to a preferred thickness of 200  $\mu$ m for electrical insulation, surface hardening, and corrosion resistance, which increases the robustness of the system **101** and reduces the possibility of a short circuit (through the vessel **102**) if the electrical insulation of the internal high-temperature wire **105a** sustains damage.

Each spacer **113** is a hollowed sleeve made of a high temperature material, such as a metal or ceramic, and is placed around the mechanical fastener **115** (e.g., rivets or screws). In an alternative embodiment, spacers **113** are formed as extensions of plate **114** as bottom plate **114** is stamped, thence formed into vertical legs that may be spot-welded or screwed to vessel **102**. The spacers **113** bear most of the compressive loads involved in keeping the bottom plate **114** and the vessel **102** intact. This is advantageous as compared to placing such loads on the TEGM **112** itself, as damage to the TEGM **112** is prevented in case the system **101** experiences a shock, such as when an object accidentally falls into the vessel **102**. Moreover, as the spacers **113** are closer to the edge of the bottom plate **114** as compared to the TEGM **112**, mechanical stability of the system **1** upon impact on the edge of the bottom plate **114** (for e.g., when system **101** is dropped) is also improved, because of the decrease in the bending moment/lever arm distance. Additionally, the spacers **113** prevent deformation of the bottom of the vessel **102** during attachment of the bottom plate **114** with the fasteners **115**. This may be particularly desirable as it keeps the bottom of the vessel **102** flat, allowing for intimate thermal contact with the flat surfaces of the TEGM **112**. The material and wall thickness of the spacers **113** may be varied to allow for more or less thermal conductance through the spacers **113** as compared to the TEGM **112**; this provides a means with which to prevent the TEGM **111** from overheating (for e.g., when the vessel **102** and the bottom plate **114** have a much larger cross-sectional area than the TEGM **112**.)

To insure optimized thermal contact while maintaining mechanical stability of the system **101**, the TEGM **112** are affixed to the vessel **2** as described herein. The bottom plate **114** may be made of a variety of high temperature resistant materials, though it may be desirable for the bottom plate **114** to be made of material having a high thermal conductivity. The thickness of (and type of material used to make) the bottom plate **114** may depend on several considerations. For example, minimizing the thickness of the bottom plate **114** may help to maintain low weight and high thermal conductance. Conversely, however, a thicker bottom plate **114** may help to preserve structural integrity of the system **101** in case it is dropped. Moreover, if the bottom plate **114** is not sufficiently thick, damage may result due to high temperature creep, or deformation may occur due to thermal cycling or thermal annealing. Keeping these and other relevant considerations in mind, the bottom plate **114** in a currently preferred embodiment is made of one eighth inch thick solution heat treated and artificially aged rolled T6 5052 aluminum.

Thermal transport can occur through a variety of different mechanisms depending on the scenario. In electrically insulating solids, thermal transport occurs primarily through phonon transfer. A phonon is an excited quantum vibrational state in which the lattice of a material oscillates at a given frequency. There is not a single vibrational frequency of phonons in a system, but rather a distribution which follows the dispersion relation. The speed of sound in a given material is the speed at which phonons (and therefore heat) is transferred through the lattice. In solids that are electrically conductive, heat is also carried by charge carriers in accordance with Wiedemann-Franz law. In gasses, thermal transport occurs through simple diffusion and convection.

In a vacuum, thermal energy is transferred through electromagnetic radiation, and is generally referred to as radiative heat transfer. Radiative heat transfer is not only limited to vacuums, but rather is omnipresent as electromagnetic energy emitted from any black body. It is well known that radiative heat transfer occurs in proportionality to the temperature raised to the fourth power; thus, radiative heat transfer is virtually inconsequential at low temperatures, and becomes increasingly dominant at higher temperatures. The thermal transport within the thermoelectric power generation system **101** described herein is generally limited to solids, with phonon transfer and radiative heat transfer being the two major transport mechanisms.

The overall thermal impedance (analogous to electrical impedance) of heat transfer from the bottom plate **114** to the vessel **102** through the TEGM **112** is decreased using the thermal enhancer **16** at the interfaces of the TEGM **112** with the vessel **2** and the bottom plate **114**. Contrarily, the spacers **113**, in conjunction with the thermal inhibitors **117**, serve to increase the thermal impedance. Resultantly, there is a larger thermal conductance through the TEGM **112** as compared to spacers **113**, which increases the power output and efficiency of the system **101**.

Further, improved thermal conductance is achieved by ensuring that phonon transport, as opposed to radiative transfer, is the dominant heat transfer mechanism in system **101** at both the macroscopic and microscopic scales, which is particularly important in the relatively low temperature regime in which the system **101** operates. For instance, to increase power output, the temperature at the interface of the vessel **2** and the TEGM **112** needs to be minimized, and radiative transfer is particularly undesirable because it causes a drastic increase in the thermal impedance at this interface. The thermal enhancer **16** serves the purpose of decreasing void space on both macroscopic and microscopic scales, allowing for the heat transfer to occur primarily by means of phonon transfer. Microscopic voids are not to be understated, as they are present at virtually all interfaces due to the finite smoothness of virtually any material surface, such as those of the alumina on the TEGM **112** and the anodized vessel **102**. The roughness of these surfaces may be minimized through careful processing, such as slow anodization and fine polishing; however, these steps may increase the cost and difficulty of the production significantly.

The thermal interface enhancer **116** developed as part of the assembly of the system **101** may be a highly malleable and thermally conductive material. The thermal enhancer **116** may be composed of a mixture of thermally conductive particles, such as metallic aluminum or aluminum oxide and high temperature grease. Metallic particles are desirable due to their superior thermal conductivity, low cost, and malleability. Malleable particles enhance thermal conductivity due to their ability to conform to surface features smaller



than the particle size, and also improve packing inside the matrix, thereby increasing the number of contacting particles. Grease may be a desirable matrix, though other highly malleable materials such as silicones may also be used, due to their singular molecular structure. The use of a matrix material may significantly decrease the number of void spaces, and may noticeably improve the thermal characteristics of system **101**, particularly at the interfaces of TEGM **112** and the vessel **102**/bottom plate **114**. The application of grease as the matrix material for the thermal enhancer **116** is advantageous due to single molecule microstructure of said grease. Single molecules can easily flow into void spaces that would be otherwise inaccessible to other suitable malleable matrix materials, such as silicones, because other materials generally comprise a more heavily bonded microstructure. These bonds (e.g. crosslinks) prevent the material from flowing into the microscopic void spaces, and therefore impede the performance of the system **101**.

Minimizing void spaces increases the rate of heat transfer in the system **101** as a more continuous path for phonon transport is then available. The particle size and the type of grease may be varied for the particular application. In a currently preferred embodiment, 30 micron aluminum particles are added to non-melting, incombustible, low migration high temperature polyalphaolefin grease. The volume fraction of particles embedded in the grease matrix may affect both the thermal and mechanical properties of the thermal interface enhancer **116**. In a currently preferred embodiment the volume fraction of particles is greater than 0.5. Polyalphaolefin greases are commercially available from TOMPAC Inc. The polyalphaolefin grease also acts as an oxygen barrier, shielding the metallic particles from oxidizing into a less thermally conductive oxide material.

This high viscosity slurry of enhancer **116**, in addition to thermally linking the TEGM **112** to the vessel **102** and bottom plate **114**, also reduces the risk of damage to the TEGM **112** when the system **101** experiences a shock (such as when it is accidentally dropped). Additionally, the particles distributed throughout the matrix physically impede the migration of grease, and prevent the movement of the TEGM **112** with respect to the vessel **102** and the bottom plate **114**. This ensures optimized thermal contact and mechanical stability throughout the lifetime of the system **101**, and allows the system **101** to better endure thermal cycling, general use, and transportation. The addition of high thermal conductivity particles to the grease may be well in excess of the percolation threshold (~16% for spherical particles) for optimized thermal conductivity and shear viscosity. This ensures maximized physical contact between adjacent particles, allowing for thermal conduction to occur through phonon transfer along a high-speed metallic pathway. Likewise, as previously noted, the interconnectedness of this pathway may prove to be a barrier to matrix migration.

The TEGM **112** are placed on the bottom of the vessel **102**, and the wires **5a** may be thermally linked and mechanically fastened to the vessel **102**. As noted, coupling the wires **5a** to the vessel **2** thermodynamically limits the maximum temperature rise available to the wire due to the presence of a phase change material in the vessel **102**.

A thermal interface inhibitor **117** may be used during assembly in order to mitigate unwanted thermal transport during the operation of the system **101**. The thermal interface inhibitor **117** is added to help increase the localized temperature differential between the vessel **102** and the bottom plate **114** at the spacers **113**, which aids in the maintenance of a temperature differential across the TEGM

**112**, and thereby increases the output voltage of the system **101**. The material selected for the thermal interface inhibitor **117** may have a thermal conductivity less than 1 W/mK. In a currently preferred embodiment the thermal interface inhibitor **117** material is a cross-linked silicone polymer fiber glass composite. Usage of this composite in the thermal interface inhibitor **117** also serves to absorb shocks and vibrations sustained by the system **101** that may otherwise be transmitted to the TEGM **112**, and therefore increases the reliability and durability of the system **101**.

Thermal conductance through the spacers **113** is minimized through controlling the phonon transport at the interface of the spacers **113** and the vessel **102**. This is achieved through the use of amorphous and low stiffness materials, which are known to have decreased phonon transport relative to materials possessing a regular lattice structure. Examples of such materials are silicones that are both amorphous and have a low elastic modulus, and glasses which are amorphous by definition. Composites may also be made by combining these two material classes, so as to increase mechanical strength and to impede phonon transport at the spacers **113**.

The thermal gasket **118** may be composed of a high temperature and flame resistant material, and serves to encapsulate and protect the TEGM **112** from environmental damage due to dirt, liquid, fuel, or combustion byproducts. The gasket **118** also creates thermal discontinuity between the vessel **2** and the bottom plate **114**. In a currently preferred embodiment the gasket **118** is made of cross-linked polydimethylsiloxane silicone rubber composite that is highly resistant to temperature, corrosion, and abrasion. A composite material is created by the addition of a second phase such as fiberglass that improves the mechanical strength and further decreases the thermal conductivity of the gasket **118**. Such a composite may be desirable for enclosing the gap between the vessel **102** and the bottom plate **114** as compared to metallic material, as the low thermal conductivity of the composite allows for a larger temperature gradient across the TEGM **112**, and thereby increases the power output of the system **101**. The gasket **118** may be made in a mold or formed in place between the vessel **2** and the bottom plate **114**. The thermal gasket **18** may also serve to dampen vibrations and shocks endured by the system **101**.

In a currently preferred embodiment, the high temperature resistant wire **105** is optimized for durability and environmental toughness. Multi-strand wires have higher conductivity than a single strand of equivalent gauge, and are more capable of withstanding higher mechanical deformation cycling sustained during regular operation of the system **101** (and its use with the voltage regulation assembly **108**). The conducting wire **105** may be insulated with a high temperature dielectric material such as polytetrafluoroethylene, cross-linked polydimethylsiloxane, or a polyimide. In a currently preferred embodiment the high-temperature wire **105** is a polytetrafluoroethylene insulated wire, inside a braided stainless steel jacket, within a polytetrafluoroethylene sleeve. The braided jacket serves to distribute a thermal hot spot over a greater length of the wire **105**, thus decreasing the risk of electrical failure due to overheating. The wire **105** is then put inside a self-extinguishing cross-linked polydimethylsiloxane-fiberglass composite sleeve. This outer sleeve adds additional thermal and abrasion protection to the enclosed wire **105**, preventing overheating and mechanical wear.

The conduit **106** protecting the high temperature wire **105** may be made of aluminum, which is easily formed to fit the



shape of the vessel **102**. Aluminum is also favorable as its high thermal conductivity prevents localized heating of the enclosed wire **105**, and the relatively high toughness of aluminum decreases the risk of damage to the wire **105** due to impact. Additionally the high-temperature wire conduit **106** is physically attached and thermally linked to the vessel **102** using a metal strap **106a**, that serves to increase both the mechanical and thermal robustness of the wire **105** by limiting the maximum temperature rise of the conduit **6** and the enclosed wires **105**.

The high-temperature connector **107** may be a 2 pin DC power connector with a molded high-temperature material, such as porcelain or glass-nylon composite housing. This connector **107** is designed for high-temperature environments where it is necessary to make DC electrical connections. An example of such a connector **107** appears in U.S. Pat. No. 6,267,626, which is incorporated herein by reference. Such connectors **107** are commercially available through a number of sources, for example, the OMEGA corporation.

When heat is applied to the heat receiving side of the system **101** (i.e., the bottom plate **114**), the initial temperature differential across the TEGM **112** is small, and hence, the voltage produced by the TEGM **112** may be too small to be useful. Additionally, during normal operation, fluctuations in the temperature of the hot and cold sinks can produce significant fluctuation in the unregulated output voltage of the system **101**, both above and below the required output voltage required to provide power to the mobile device **111**. Additionally, when a large thermal difference is experienced by the TEGM **112**, the output voltage of the generation system **101** may be above the voltage required by the mobile device **111**, which, if unregulated, may damage the device **111**. In a currently preferred embodiment, the challenge of providing a stable output voltage to the mobile device **111** is overcome through the use of a commercially available pulse width modulation (PWM) DC to DC voltage conversion circuit **109a** contained in enclosure **109**. Thus, voltages below those needed by the mobile device **111** are boosted, and voltages above those needed are reduced to the desired output voltage. Recent advances in the art of pulse width modulation DC/DC conversion electronics allow these circuits to operate with over 90% efficiency, and allow them to occupy relatively little physical space. This allows for the voltage regulation assembly **108** to be highly compact and lightweight. State-of-the-art voltage regulation pulse width modulation controllers are commercially available from a variety of providers, including, for example, Maxim and Texas Instruments.

Physical separation of the power regulation electronics **9a** from the heat source **104** and the vessel **102** via the temperature resistant wire **105** serves to protect the power regulation electronics **109a** from damage due to overheating. Additionally, the power regulation circuit enclosure **109** provides physical protection to the regulation circuit **9a**. The circuit enclosure **9** may also be filled with epoxy to protect the voltage regulation circuit **9a** from damage due to shock or moisture. High thermal conductivity epoxy is preferred as it prevents overheating by conducting heat generated by the regulation circuit **109a** during operation. The standard electrical connector **100** may extend from the circuit enclosure **109** or may be contained within the circuit enclosure **109**. The power regulation assembly **108** is electrically coupled to the generation system **101** through the high temperature connector **107**. This allows for the regulation assembly **108** to be detached from the system **101**, thereby increasing the

ease of transportation and storage of the system **101**. Additionally the power regulation circuit **109a** may be modified for different output voltages with distinct regulation assemblies **108** tailored to the desired application. Detachability of the regulation assembly **108** allows for the same generation system **101** to be used interchangeably with different regulation assemblies **108**, as may be required for different devices **111**.

A method **200**, implemented by a combination of circuitry in a smart load **111** and in the DC-DC regulation circuit **109a** within module **109** is illustrated in FIG. **16**. This method starts **202** with a user connecting **204** a power source, whether it be a thermoelectric generator system **101** or a photovoltaic panel **5** to the regulation circuit **109a** and the regulation circuit **109a** to the smart load **111**. Actions performed within the regulation circuit are on the left side of FIG. **16**, while those within the smart load **111** are on the right side of FIG. **16**. The regulation circuit **109a** then provides **206** a voltage meeting the standard voltage level, which for a USB-compatible smart load is five volts, to the smart load. In an embodiment, the regulation circuit waits for voltage and current provided by the power source to reach a minimum value before providing power to the load. The regulation circuit also estimates an amount of power available, and in embodiments configures an interface to provide a power-available indication to the smart load, thereby communicating the amount of power available to the load. In a particular USB embodiment, this power available is indicated by voltages on data pins of the USB interface. In an alternative embodiment, the regulation circuit configures itself to interact with the smart load using a serial handshake over the interface to indicate compliance with a particular standard of interface that implies particular amounts of power available to the load, and thereby communicate the amount of power available to the smart load.

Once power is provided **206** to the smart load **111**, the smart load recognizes **208** that power is present and determines **212** an amount of power available by reading voltages of data pins of the interface with the regulation circuit, or by interacting serially with the regulation circuit. Once the amount of power available is determined, the smart load configures its battery-charging circuitry to use an amount of power not exceeding the amount of power available. In a USB-compatible embodiment, the smart-load configures itself as a USB-1, USB-2, or a USB-3 compliant load by setting the battery charging circuit to draw a corresponding low, medium, or high current from the regulation circuit, where the current drawn by the battery charging circuit is as high as practical while remaining within the amount of power available.

The regulation circuit or power controller then continually monitors **214** current drawn by the load, while the load continues to charge **216** its battery. The regulation circuit or power controller provides visual indication of load current as previously described. The power controller also periodically determines that the amount of current drawn by the smart load **111** is appropriate for an amount of power available from the power source **5**, **101**. It should be noted that power used by a smart load may often exceed the amount of power used by the battery charger of the load because the load may, for example, use power for other functions; in an embodiment where the load is a cell phone or tablet computing device, the smart load may operate a processor and a radio to communicate with cell towers. If the power available is appropriate, no change **220** to configuration is required. If a large excess of power is available and not being used, or if the current drawn by load **111** is less



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than the amount of power available, the power controller determines that a change **222** to configuration is required.

If a change in configuration is required to optimize battery charging time, the power controller/voltage regulator circuit **109a** resets **224** the load by, in an embodiment, disconnecting power to the smart load. In an alternative embodiment, the power controller uses another method of communicating a reset signal to the load, such as a serial reset command. The smart load then recognizes **226** the reset condition, preparing itself **228** for reconnection to power resulting in a new power-on condition **208** or an end-of-reset condition; and, in an embodiment after a timeout of one-half to five seconds, the power controller resumes providing power **206** to the load, and updates its estimate **210** of power available and load power consumption.

Many different arrangements of the various components depicted, as well as components not shown, are possible without departing from the spirit and scope of the present invention. Embodiments of the present invention have been described with the intent to be illustrative rather than restrictive. Alternative embodiments will become apparent to those skilled in the art that do not depart from its scope. A skilled artisan may develop alternative means of implementing the aforementioned improvements without departing from the scope of the present invention.

In an embodiment of the method of FIG. **16**, the power controller initially estimates a low level of power available, and configures the load accordingly. After a first interval of time, if the power source has not become overloaded, the power controller estimates a mid-level of power available, resets the load, and configures the load accordingly; if the power source continues as not overloaded for another first interval of time, the power controller estimates a mid-level of power available and configures the load accordingly. If the power source becomes overloaded, the power controller immediately backs down by one level of power available, resets the load, and configures the load accordingly. Once an appropriate load configuration that does not overload the power source, if the power provided is maximum the power controller continues providing power indefinitely. If the power provided is less than maximum, the power controller provides power to the load for a second interval of time, greater than or equal to the first interval of time, then periodically resets the load to try a higher power configuration. The system therefor hunts for an optimum setting of the battery charger in the load.

Changes may be made in the above methods and systems without departing from the scope hereof. It should thus be noted that the matter contained in the above description or shown in the accompanying drawings should be interpreted as illustrative and not in a limiting sense. The following claims are intended to cover all generic and specific features described herein, as well as all statements of the scope of the present method and system, which, as a matter of language, might be said to fall therebetween. It is also anticipated that steps of methods may be performed in an order different from that illustrated and still be within the meaning of the claims.

What is claimed is:

1. A power control device comprising:

voltage-regulation circuitry configured to couple power from a power source to a load, the load configurable to receive power at least at a first and a second power-reception level, the second level greater than the first level;

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power monitoring circuitry adapted to detect an overload of the power source and to indicate on a display a power absorbed by the load;

signaling circuitry configured to signal circuitry of the load with information regarding a power availability level at the power control device;

resetting circuitry configured to reset the load when the power source is incapable of providing sufficient power to the load at the second level, and to use the signaling circuitry to instruct the load to receive power at the first level; wherein

the resetting circuitry is further configured to periodically reset the load to the second power reception level when the load is receiving power at the first power-reception level and the power monitoring circuitry is not indicating overload of the power source; and wherein the power source comprises a solar panel.

2. The power control device of claim 1 wherein the power source comprises a thermoelectric generator.

3. The power control device of claim 1 wherein the voltage regulation circuitry has a USB connector configured for coupling to a load, and wherein the circuitry for resetting the load comprises circuitry for removing power from the USB connector for a period of time.

4. The power control device of claim 3 wherein the signaling circuitry comprises circuitry configured to apply voltage levels to data pins of the USB connector, the voltage levels being static levels indicative of a power-reception level.

5. The power control device of claim 3 wherein the signaling circuitry comprises circuitry adapted to serial communications with a load.

6. The power control device of claim 3 wherein the power monitoring circuitry comprises a bar-graph display of power absorbed by the load.

7. The power control device of claim 1 wherein the power monitoring circuitry comprises a bar-graph display of power absorbed by the load.

8. A method of operating a smart load with a charging system comprising:

applying power to the smart load;

Estimating an amount of power available from a solar panel of the charging system;

communicating the amount of power available from the charging system to the smart load;

configuring a battery charger of the smart load to accept from the charging system an amount of power less than the amount of power available;

monitoring an amount of power absorbed by the smart load;

determining whether a change in configuration is required to optimize charging time of a battery in the smart load; and

resetting the smart load and communicating to the smart load a different amount of estimated power available to the smart load.

9. The method of claim 8, wherein power is applied to the smart load through a USB connector, and wherein resetting the smart load comprises removing power from the USB connector for a period of time.

10. The method of claim 9 wherein the communication is performed by applying static voltage levels to data pins of the USB connector.

11. The method of claim 9 further comprising displaying power absorbed by the load on a bar-graph display.

12. An apparatus comprising:  
coupling circuitry configured to couple power from a  
solar panel to a load, the load configurable to receive  
power at least at a first and a second power-reception  
level, the second level greater than the first level; 5  
current measuring circuitry adapted to measure a current  
coupled into the load by the coupling circuitry;  
display circuitry adapted to indicate a current measured  
by the current measuring circuitry; and  
resetting circuitry configured to reset the load when the 10  
current measuring circuitry determines the load is  
attempting to draw power at the second power-recep-  
tion level and the power source cannot provide suffi-  
cient power to the load at the second power reception  
level; and wherein the resetting circuitry is further 15  
configured to periodically reset the load to the second  
power reception level when the load is receiving power  
at the first power-reception level.
13. The apparatus of claim 12 wherein the display cir-  
cuitry comprises a plurality of discrete light-emitting ele- 20  
ments, and wherein the current measured by the current  
monitoring circuitry is indicated by illuminating a number of  
light-emitting elements determined according to a level of  
the measured current.
14. The apparatus of claim 12 wherein the coupling 25  
circuitry comprises voltage regulation circuitry.

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